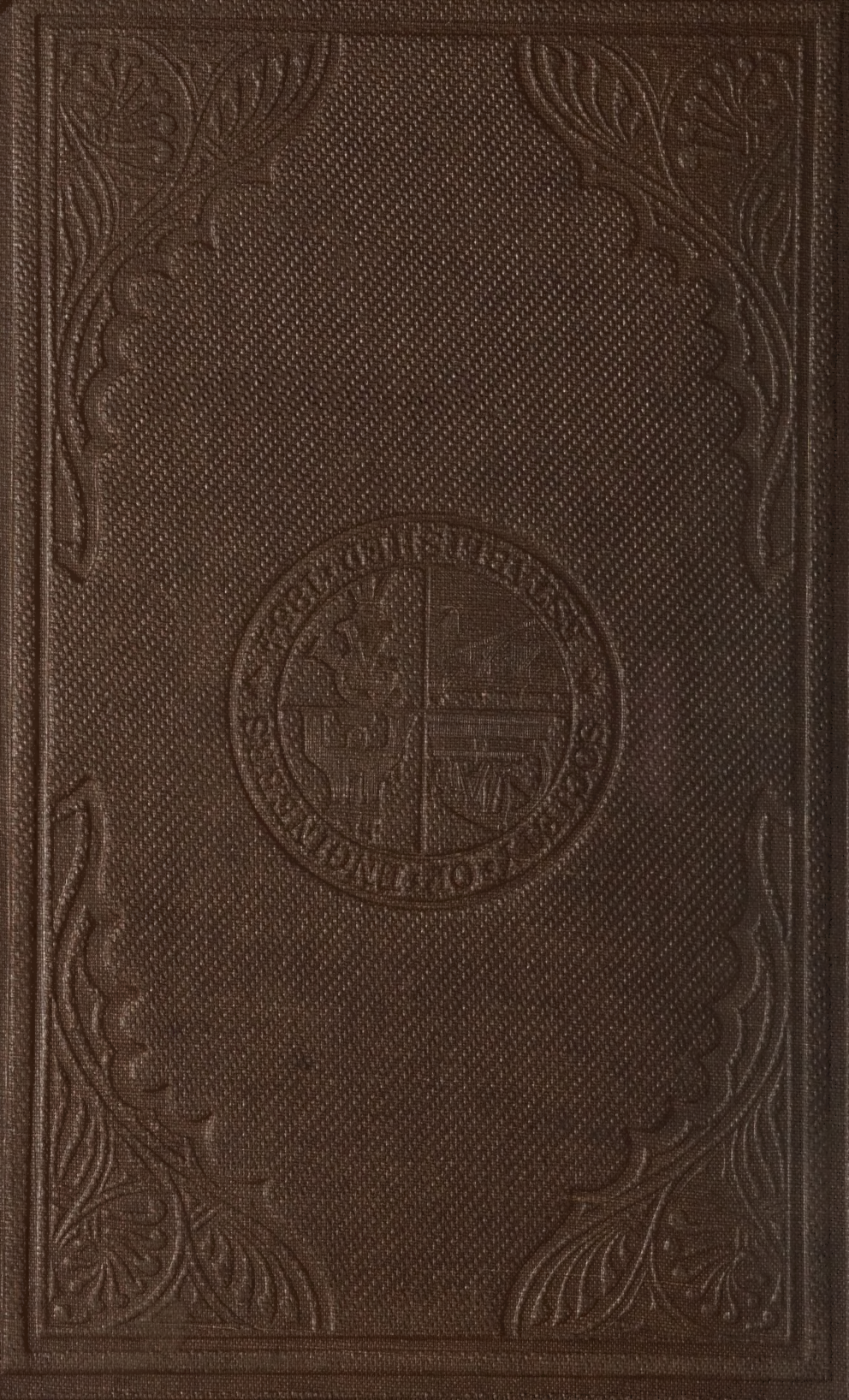
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SOCIETY OF ENGINEERS.

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EDITED BY

CHARLES J. LIGHT, Memb. Soc. Eng.,
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PREMIUMS FOR 1885.

At a meeting of the Society, held on February 1st, 1886, a Premium of Books was awarded to:

WILLIAM NEWBY COLAM, for his Paper on "Cable Tramways."

And to:

JOHN BALDRY REDMAN, M. Inst. C.E., for his Paper on "Tidal Approaches and Deep Water Entrances."

McElroy
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SOCIETY OF ENGINEERS.

ESTABLISHED MAY, 1854.

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PLACE OF MEETING:
THE TOWN HALL, WESTMINSTER.

1886.

TRANSACTIONS, &c.

February 2nd, 1885.

INAUGURAL ADDRESS.

By CHARLES GANDON,

President.

It seems to be a time-honoured rule for presidential addresses to commence with an acknowledgment of the honour conferred upon the President by his election, and upon this occasion I think I cannot do better than follow this good example by tendering you my sincere thanks for the compliment paid to me by my election to the post of President of this Society. Be assured, Gentlemen, that I am deeply sensible of the honour and proud to occupy the position, although I have grave doubts as to my ability to perform the duties belonging to it so as to merit your satisfaction, and to promote the best interests of the Society; but I trust you will believe in my desire to do so, and that my best efforts will be exerted in that direction. I have long taken great interest in the progress of the Society, and having had the honour of being for some years a Member of the Council, I am sure that I have no easy task before me; but knowing the hearty support and assistance my predecessors in this chair have always received, not only from the Council, but from the Members generally, I venture to hope that the same kindness will be extended to me, and that my shortcomings will not be attributed to indifference or neglect.

The financial and general position of the Society having been already explained this evening, it will be unnecessary for me to refer to it, but I must express my regret that the classes of lectures, so successfully started in the session of 1883, did not meet with the same support during the last session, and, not feeling justified in applying the Society's funds towards the expenses of these lectures when they are not self-supporting,

the Council has reluctantly determined to suspend them for the present year, with the full intention, however, to renew them again so soon as circumstances will permit. I look upon this suspension of the lectures with much regret, feeling convinced that they have been of great benefit both to the Society and to those who have attended them.

For our ordinary meetings of the past year, we were fortunate in obtaining some most interesting papers, leading to very useful discussions. The first, on March 3rd, was contributed by Mr. A. C. Engert, on "The Defects of Steam Boilers and their Remedies." It was pointed out that the principal defects were the heat passing away too quickly, incrustation, unequal expansion, formation of smoke, loss of unconsumed gases, and priming. Mr. Engert described a boiler designed by himself, by which he considered he had minimised these evils, and which was stated to be capable of evaporating 11·3 lb. of water per pound of coal used.

At the next meeting, on April 7th, Captain W. B. Barker, U.S.A., described "An International System of Marine Course Signalling," by means of short and long blasts from a steam-whistle. The subject was one with which, perhaps, but few of us were conversant, but any means for increasing the safety of travelling by sea must of necessity be of interest, and the plan described in the paper certainly appeared likely to effect this.

On May 5th, Mr. H. Stopes read a paper on "The Engineering of Malting." The antiquity of beer and malt was referred to, they having been known to the ancient Egyptians; and the various modes of malting, with the buildings and apparatus required, were described.

The fourth paper, read on June 9th, by Mr. J. C. Fell, was on "Soft *versus* Hard Water for Manufacturing Purposes." The chemical distinctions between these two qualities of water were explained, the various methods for softening hard water described, and much information was given which would be appreciated by all who have had to contend with hard water for steam-boilers, or for distilling, brewing, or bleaching.

Mr. Perry F. Nursey's paper on "Modern Bronze Alloys," read on October 6th, after the summer recess, was as interesting as the numerous communications from that gentleman at all times are, and many of us were doubtless surprised to learn the large number of these alloys which are in use, no less than eleven different compositions being mentioned and described in the paper.

The next paper, on November 3rd, was by Professor

Wanklyn, on "The Cooper Coal-liming Process," which consists in the admixture of a certain proportion of slaked lime with coal for gas-making before it is charged into the retorts: this arrests a portion of the sulphuretted hydrogen, carbonic acid, and other impurities, and the ordinary purifying process is rendered easier. This process is being successfully worked at Tunbridge Wells, but at other places, where it has been experimented with, equally good results have not always been obtained; the success at Tunbridge Wells being probably due, to some extent, to the coal there being broken up very small and the lime intimately mixed with it.

The seventh and last paper, on December 3rd, was another contribution from Mr. A. C. Engert, on "The Blowpipe Flame Furnace." At a first glance, this title might seem to refer to some furnace for metallurgical or laboratory purposes, but it proved to be a new form of steam-boiler furnace with which, by a particular arrangement for the admission of the air at the furnace-door, and a baffle-plate interposed between the door and the fuel, a kind of blowpipe action is produced, and more perfect combustion obtained. Mr. Engert claims to have obtained an evaporative power of 13·02 lb. of water per lb. of coal, which is an improvement even upon the boiler described by him in his previous paper.

All these papers were of considerable interest, but, after careful deliberation, the Council decided to award two premiums of equal value—one for Mr. Engert's first paper on "The Defects of Steam Boilers and their Remedies," and the other to Mr. J. C. Fell for his paper on "Soft *versus* Hard Water for Manufacturing Purposes."

Next to the papers read at our ordinary meetings, the summer trips are perhaps the most interesting and best appreciated business of the Society, and there is every reason why this should be the case, as they afford Members and their friends opportunities for studying engineering works of every description in practical operation, to which access could not otherwise be obtained. These visits have now been carried out for so many years that nearly all the most noted works within an approachable distance of London have been inspected, and it might be thought that the list is now exhausted, but new industries are constantly being started, and many of the places already visited have undergone such changes that they well repay a second or even a third visit, and I think there need be no difficulty in finding places of interest for the future.

The first visit during the past year was made, on June 25th, to the Midland Railway Company's locomotive and carriage

works at Derby, where we were most kindly received by Mr. S. W. Johnson, the locomotive superintendent, and Mr. T. Clayton, superintendent of the carriage department. Other works of a similar character have been visited upon former occasions, but these are perhaps the largest and best-equipped works of their kind in the kingdom; they possess a completely fitted laboratory for testing all the materials used, and all descriptions of work are carried on necessary for the complete construction and repair of the company's extensive rolling-stock, as well as the casting, among other things, of all the chairs required for the permanent way, 200 to 250 tons of these chairs being turned out weekly. Some idea of the extent of the operations carried on at these works may be formed from the fact that the company have upwards of 1700 locomotives in use.

The second visit was projected to the Tilbury Docks, then in course of construction, but, owing to the work at that place being unexpectedly suspended, this visit had unfortunately to be given up at the last minute.

On August 21st, we were afforded an opportunity of inspecting the new works now being erected by the South Metropolitan Gas Company at East Greenwich. To say that we were received by the present chairman, Mr. George Livesey; the chief engineer, Mr. Frank Livesey, and the secretary, Mr. Frank Bush, is sufficient proof that we were cordially welcomed, and that every effort was made to render our visit agreeable and instructive. In the year 1881 the Society paid a visit to the same company's then only works in the Old Kent Road, but since that time a considerable change has taken place in the company's position. It then had, as I have said, only the works in the Old Kent Road, and a paid-up capital of 500,000*l.*, but it has since amalgamated with the Phœnix and Surrey Consumers' Gas Companies, and has a subscribed capital of over 2,200,000*l.*, with five manufacturing stations; it has also quite recently further amalgamated with the two companies supplying gas to Woolwich. In consequence of these amalgamations, it was considered desirable to establish works in a more suitable locality; for this purpose the site at East Greenwich, of over 130 acres, which we last visited, was purchased, where works on a very large scale are being erected. Although this site is in many respects admirably suited for its purpose, yet it presents some engineering difficulties. The general surface of the ground is, or was, about 6 feet below Trinity high-water mark; precautions have consequently had to be taken to guard it against floods; a river wall 1400 feet long, and a landing pier projecting 390 feet into the river, have been built.

In excavating for foundations and gasholder tanks, large quantities of water have had to be contended with, and, on account of the treacherous nature of the ground, it has been necessary to go a considerable depth with the foundations of all buildings. The manufacturing plant will be in twelve blocks, each capable of producing 5,000,000 cubic feet of gas per day. Not the least interesting portion of this visit was the inspection of the chemical works of Messrs. Sadler, Forbes, Abbott & Co., to whom we are also greatly indebted, as such works are, as a rule, jealously closed to strangers.

The last, and perhaps, to many of us, the most interesting visit, was to the electrical engineering works of Messrs. Siemens Brothers, at Charlton, on September 10th. I believe this is the third time the Society has been afforded the opportunity of going over this wonderful establishment. Those who have been on former occasions will have a lively recollection of the hearty reception accorded them by one whose death was felt to be a loss to the whole world—I refer to the late Sir William Siemens; and on this last occasion of our visit his successors in the business received us with the kindness that might have been expected from their connection with one who was at all times ready to impart his knowledge to others. At the time of our visit the cable ship *Faraday* was taking in the second portion of the Mackay-Bennett Anglo-American cable, 700 miles in length, for laying between Newfoundland and Nova Scotia, the first portion, from Ireland to Newfoundland Bank, 1700 miles long, having been previously made and laid by the same firm.

The civil engineering profession of the present day embraces so many different subjects and branches that it would be difficult to enumerate them all: looking back to the beginning of the present century, it would seem that such a profession scarcely existed, or that it included very few subjects beyond road and canal making. It has frequently been asked, what constitutes a civil engineer, and I am afraid this is still somewhat difficult to answer. One of our Past Presidents remarked that the profession occupied a position which was neither creditable nor satisfactory; and this I think is still true, for it is certainly unsatisfactory that any one can dub himself C.E. without possessing qualifications or credentials for so doing. That this should have been the case fifty years ago is not surprising, as there were then few opportunities for acquiring a theoretical training in engineering subjects; but at the present time such opportunities are so general that all who contemplate entering the engineering profession should commence by mastering at

least some of the subjects connected with it. The necessity for some competent examining body, authorised to grant certificates or diplomas of proficiency, has also long been recognised, but we seem unable to get beyond discussing and admitting this necessity.

The development of the use of steam for motive power has, perhaps, contributed more than anything else to the extension of the civil engineering profession, for without it the means of locomotion, both by land and by water, would not have obtained their present proportions. Railways may be considered one of the principal branches, and when it is remembered that in the United Kingdom alone the capital invested in railways exceeds 800,000,000*l.* sterling, it will be evident that the expenditure of this enormous sum, within about half-a-century, must have vastly increased the importance of the profession. Water transport has also made gigantic strides, chiefly by the aid of steam and the employment of iron and steel for ship-building, and these two great means of locomotion have necessitated the construction of docks and harbours of dimensions suited to the growing proportions of the trade.

One marked feature of modern times is the increasing use of steel for structural and other purposes, for which it is steadily supplanting iron, on account of improvements and economies effected in its manufacture by the Bessemer, Siemens, Martin, Thomas, Gilchrist, and other processes. Steel rails may now be bought as cheap as, and sometimes cheaper than, iron ones, and its superior strength enables it to be used with considerable economy where lightness is also an advantage. At the same time so many qualities are now produced that it is somewhat difficult to determine where the metal ceases to be iron and becomes steel, and in its use considerable judgment is required to determine the quality suitable, and to be sure that it is obtained. As an illustration of its superior strength, it may be stated that steel wire can be produced capable of bearing a tensile strain equal to 100 tons per square inch. Perhaps one of its most remarkable applications is to heavy ordnance and armour-plating of ships of war; and, when we consider the remarkable progress that has been made in this direction, it seems doubtful whether it should be regarded as a boon or a curse to mankind. It is difficult to speculate where the increase of power and size of engines of warfare, and the means for resisting them, will cease, for no sooner are ships built capable of resisting the heaviest guns than more powerful guns are produced. We now have guns weighing 100 tons, carrying projectiles of 1500 lb., and charged with 450 lb of powder, and it was recently reported

that a gun weighing 130 tons was in course of construction for the Italian Government.

It does not seem that any great engineering discovery has been brought forward during the past year, but I think steady and satisfactory progress has, on the whole, been made. Among engineering works of interest now in progress may be mentioned the Severn Tunnel, the construction of which has been long in hand, but it is now fast approaching completion. It will provide a more direct route for the Great Western Railway into South Wales; the present line, from Bristol, runs a considerable distance up the east bank of the Severn to Gloucester, in order to cross the river, and then returns down the opposite bank. The tunnel will provide a straight cut from Bristol to Newport, saving a distance of nearly fourteen miles. It is by far the most extensive work of its kind ever undertaken, and, compared with it, the Thames Tunnel sinks into insignificance, although the Mersey Tunnel between Liverpool and Birkenhead—now also nearly completed—is no mean competitor. The Severn Tunnel, when completed, will be 4½ miles long, of which 2½ miles are 80 to 100 feet below the bed of the river. The plan adopted for the excavation was, in the first place, to run a boring 7 feet diameter through the entire length; gangs of men were then set to work at numerous points to enlarge this to the required size, thus enabling the work to be proceeded with more rapidly than if the tunnel had, in the first instance, been worked to its full size from both ends only. The material bored through was for the greater part sandstone, and, as might be expected, water was one of the principal difficulties to be contended with, although this came more from land springs than from the river; but pumping machinery capable of raising 50,000 gallons per minute was required for keeping the working clear. The work has been in progress since 1873, and upwards of 3000 men have at times been employed, for whose accommodation quite a little town—with hospital, club, &c. — has sprung up on the Monmouthshire shore of the river.

Another important work has also been completed during the past twelve months in establishing the connecting link of the inner circle of the Metropolitan Railway. This comparatively short line, the total length of which was only 1200 yards, cost about 2,000,000*l.*, and has required more engineering skill than would be necessary for hundreds of miles of ordinary railways, having had to be carried out beneath the streets and buildings of the busiest part of the Metropolis; the greater part of the buildings in Cannon Street had to be underpinned, and new

cellars and foundations formed for them without interruption to the traffic in the street.

This short reference to some of the principal engineering works finished or in progress during the past year would be incomplete if mention were not made of the Forth and Tay Bridges, the former now being erected from the designs of Messrs. Fowler and Baker, and the latter from the designs of Mr. W. H. Barlow, by Messrs. Tancred, Arrol and Co., the contractors. The Forth Bridge, which is to form the railway connection between Queensferry on the south bank of the Forth, to the Fife or north bank, crosses the Forth a short distance above Leith at the point where the island of Inchgarvie lies in the middle of the stream; it will consist of two spans of 1700 feet each, two of 675 feet, fifteen of 168 feet, and five of 25 feet each; the total length being about 1½ mile; the headway under the centre of bridge will be 150 feet above high-water mark, and the highest portion of the bridge 361 feet above the same level. The contract for this bridge was 1,600,000*l.*; it was commenced in January 1883, and it is expected to take between five and six years more to complete. The design and mode of construction of the larger spans is original and peculiar; steel enters largely, if not almost exclusively, into the upper or bridge portion. A very interesting account of its details was given by Mr. Benjamin Baker at one of the meetings of the British Association in Canada last year.

The Tay Bridge, to replace that destroyed by the fatal disaster of December 1879, presents, perhaps, fewer novelties in its details of construction, but is, at the same time, a remarkable specimen of engineering design. It will consist of eighty-five spans, having a total length of over 10,500 feet, or nearly two miles. The contract sum for its erection is 700,000*l.*, being less than one-half of that for the Forth Bridge notwithstanding its greater length, but considerable outlay has been saved by utilising the piers of the former bridge, and its height above water-level is less.

I have said that, to my mind, the application of steam to locomotion has done more than anything else to extend the profession of the civil engineer, and I think it has also contributed in the greatest degree to the comfort and convenience of mankind. If we consider the facilities now available for reaching the most remote places by its aid, it is difficult to conceive how the world existed without it in the past, or what would be the consequences of having to do without it in the future. Complaints loud and deep are frequently made as to the short-

comings of our railway administrations, and but few reflect how great and continuous the improvements have been; but it will be within the recollection of many that third-class passengers had, at one time, to travel in uncovered carriages—or rather trucks—and even in some cases seats were not provided; now we complain if these carriages are not cushioned and curtained, and many of our first-class carriages are perfect models of comfort and luxury. Then, again, as to unpunctuality; it is, of course, very annoying to arrive a few minutes late, and thus miss an appointment or another train; but, with the enormous development of the traffic which has arisen at all populous centres, it can scarcely be a matter of surprise that delays should occur at times. Some idea may be formed of the present magnitude of the railway traffic of the United Kingdom from statistics published in the *Times* of November 3rd last, according to which there were, at the end of the year 1883, 18,681 miles of double, or more than double, lines of rails; the train mileage run during the year amounted to 268,897,236 miles; the number of passengers carried was 683,718,137, exclusive of 632,000 season-ticket holders; the goods and minerals carried amounted to 266,383,968 tons, and the total receipts were 71,062,270*l.*

To the application of steam to locomotion by land and by sea, we are indebted for the enormously increased facilities of intercommunication both personally and by correspondence, and one of the most important branches of engineering is perhaps the improvement of the steam-engine and its accessories, and although they may now be said to have reached a high degree of perfection, yet it is to be hoped that some improvements remain to be made. In reading Lord Rayleigh's learned and interesting address to the members of the British Association at their gathering in Canada last year, I felt some surprise at his remarks regarding the efficiency of the steam-engine; he said it was popularly supposed that the actual work obtained from engines of the best construction falls very far short of what they theoretically should perform; but he maintained, on the contrary, that there is no great margin left for improvement. The noble and learned president said that "the fraction of the total energy which can be converted into work depends upon the relative temperatures of the boiler and condenser," and that "it is impossible to utilise all the energy which, according to the first law of thermo-dynamics, is resident in the coal." This is undoubtedly true, and I do not suppose that those who have attempted to show the proportion between the theoretical energy due to the combustion of the fuel and the duty actually

obtained, imagined, or intended to suggest, that the whole of this energy could be utilised; but the comparison seems to be useful, and I think the available proportion of the energy is dependent upon other details as well as the relative temperatures of the boiler and condenser, in which improvements may still be hoped for. The combustion of the fuel is certainly not perfect in present practice, and better means may be found for conserving the temperature of the steam; but little also seems to have been done with the use of very high-pressure steam, although Perkins has proved something of what may be done in this direction.

I would now refer to some of the minor branches of civil engineering, more closely connected with our domestic well-being. As compared with railways, ship-building, dock and harbour works, these branches are insignificant with regard to the amount of money employed, but they are none the less important. Perhaps the most important one is the supply of water for domestic, manufacturing, and sanitary purposes. It might be possible to dispense with railways, electric telegraphs, and so forth, but a good and sufficient supply of water is one of the first necessaries of life. It seems difficult to obtain any condensed information with reference to the general water supplies in the United Kingdom, but I find that London, with its four millions of inhabitants, is supplied by eight companies, having a capital of over 13,000,000*l.*, and supplying about 140 millions of gallons of water per day, or an average of 35 gallons per day per head, and the capital employed in the water supplying undertakings of the United Kingdom probably exceeds 50,000,000*l.* It may be fairly assumed that no country is better supplied than England with this most essential requisite for the health of its inhabitants, although there are places where the quantity supplied per head is larger; for instance, in New York the quantity per head per day is said to exceed sixty gallons.

Quantity, however, is not the only essential in a good water supply; quality and pressure are also important elements. Of course, rivers are the most available sources for obtaining supplies, but they are in most cases unsuitable, on account of contamination from drainage, and, in our densely populated country, it would probably be difficult to find a river free from this objection, unless the supply can be drawn at or near its source. The supplies obtainable from the chalk formations, such as underlie London, are less open to this objection, although good authorities have recently asserted that they are not in all cases entirely free from it, and as the water con-

tains a considerable quantity of lime, it is hard and unsuitable for manufacturing and domestic purposes, other than for drinking.

Another important advantage of a good water supply is the protection it affords against fire. For this to be efficient, a constant and abundant supply is needed at a good pressure, and available at all points. Until within the last few years most of our large towns have been dependent upon fire-engines for furnishing sufficient pressure, but efforts have of late been made to establish constant high-pressure supplies, admitting of the employment of hydrants, which, being constantly at hand, and available by simply attaching hose-pipes, have an undoubted advantage over fire-engines, provided a general and constant high-pressure service of water can be depended upon. In many of our larger towns, such as Glasgow, Dublin, Liverpool, and Manchester, supplied by gravitation from points considerably above their level, this is easily obtainable; but in London, where means have not yet been devised for a gravitation supply, and the water has to be pumped, the average pressure is, in many parts, quite insufficient for fire purposes, although hydrants have been introduced in some parts of the City. The importance of this part of the water supply of a town will be evident when it is stated that the annual destruction of property by fire in London is estimated to exceed 2,000,000*l.* sterling, even with our present efficient fire brigade, and that by the introduction of hydrants at Manchester, Mr. Bateman estimates the loss by fire has been reduced to one-seventh of what it before was.

Much dissatisfaction has of late been expressed against the metropolitan water companies on account of the unequal mode of assessing the charges for water supply. Not being conversant with the many points involved in this complicated question, I do not wish to express a decided opinion upon it, but it does appear to be an anomaly that a tenement should be charged for its water supply according to its rental value, gross or net, without any regard to the quantity of water consumed. If reliable details were collected, it would probably be found that the cases of unfair or excessive charge are comparatively few, and that the majority of the consumers, particularly the poorer classes, pay but a very moderate amount for the water they consume. It may also be admitted that, if discrepancies cannot be avoided, the poorer classes should be favoured, but still it would seem fairer for all if the charge could be based upon the actual consumption, although this is not without difficulties and disadvantages. In the first place, it would necessitate an

expensive system of meters for ascertaining the consumption, which would add materially to the cost of distribution and collection; and, secondly, it would create an inducement for the poorer classes to exercise undue economy in their use of water, thus increasing the danger of disease from uncleanliness, while it would also probably result in diminished revenues to the companies, thus reducing their profits or necessitating higher rates. There can be but little doubt that, under the existing conditions, some consumers are overcharged, but as a rule, the water companies do not appear to realise excessive profits, so that any readjustment of the rating would probably have the effect of relieving the richer at the expense of the poorer consumers. This appears to me to have been the result of the celebrated Dobbs case, which probably effected a welcome reduction of a few shillings per annum for some, but it has put the water companies to considerable expense, and set them to looking for consumers who were undercharged, of which there were many.

Of course, anything in the shape of a monopoly is repugnant to the free-born Briton, and it requires but few arguments, good, bad, or indifferent, to convince the British public that it is being imposed upon by the existence of such monopolies as water and gas companies possess, and these companies get but little credit for endeavouring to carry out their obligations fairly towards the public, but it is doubtful whether, in most cases, any advantage is obtained by such undertakings being in the hands of public bodies. Water, being a necessary of life, there is perhaps less to be urged against the supply being in the hands of local authorities than in the case of gas, but with the latter I can see no more, and perhaps even less, reason for gas being so supplied than there would be for similar authorities to acquire railways, or indeed to undertake the exclusive supply of bread or meat. It is true that the latter necessaries are open to competition, but they are unrestricted as to the amount of profit which may be realised by their sale, and it seems to me that the public might be more benefited by being able to obtain bread and meat at low prices than by doubtful reductions on the cost of gas from its being supplied by local authorities.

The next branch of what I would call domestic engineering, to which I would refer, is the supplying of coal gas for lighting, heating, and other purposes. The first London gas company (the Chartered) was established in the year 1812. The progress made in its use was, however, slow at first, and the earlier companies met with little success for a considerable time, so

that its more general use cannot be said to date back for more than fifty years. Now, from a Parliamentary return made for the year 1883, I find that the capital employed by the authorised gas undertakings in the United Kingdom amounted to nearly 52,000,000*l.*; 7,631,304 tons of coal were used for the production of gas during that year; there were 2,019,846 consumers, and 375,536 public lamps. These figures are insignificant in comparison with railway statistics, but they show that the gas industry has become an important one, and, notwithstanding the objections urged against its use by some, I venture to think it will continue to prosper, and the demand for it increase, not only as an illuminant, but for numerous other purposes. For heating and cooking its use is increasing greatly; it is invaluable for laboratory and many metallurgical purposes; it is being adopted in bakers' ovens and enamelling furnaces, and the employment of gas-engines seems chiefly limited to the power of the makers to produce them.

It is frequently said that but few improvements have been effected in gas manufacture since its first introduction, and, in so far that gas is still made by distilling coal in retorts, extracting its impurities by condensers, washers, scrubbers and purifiers, storing it in gasholders, and finally distributing it through mains, there may be some truth in this assertion; but, if the general process has remained the same, great improvements have been made in the details, by means of which the cost of production has been much reduced and the quality improved. That coal has remained the source from which it is made, and that the mode of distillation has not greatly changed, proves only that, at least for the present, these are found to be the most suitable means, although innumerable other substances have been from time to time proposed, tried, and abandoned. In the retort-house the make of gas per ton of coal and per retort has been largely increased, and the consumption of fuel reduced; and regenerative firing is being adopted in many places, by which still further economies may be hoped for. Mechanical stoking is also largely engaging the attention of gas engineers, and has been introduced into many works with marked success.

In all directions evidences may be found of economies introduced, both in the cost of gasworks plant and in the working, but in many cases there still appears to be room for improvements. The capital employed per ton of coal carbonised annually, varies in England, in cases that I have seen, from 2*l.* 6*s.* 6*d.* to 18*l.* 11*s.* 8*d.*, and the cost of producing and distributing the gas from 10·43 pence to 36·40 pence per

1,000 cubic feet. It must not be supposed that these costs could be in all cases equalised—the size and position of the works, the cost of the coal, and numerous other details, must necessarily have great influence, both on the cost of the plant and the production; but it would be easy to give instances where similar conditions exist, and where there are wide and unjustifiable variations in the expenditure.

Sanitary engineering is another branch of our profession which has become recognised within comparatively recent times, and, if it be taken to include sewerage, drainage, and the warming and ventilating of buildings, it is one which I think still requires much attention before it can be said to be well understood, or efficiently practised. On some of these points we have still much to learn from other countries. In the matters of sewerage and drainage, we sometimes claim to be in advance of our neighbours, and this may perhaps be the case, if the low death-rates in most of our large towns can be taken as a criterion, but the state of the Thames and many other of our large rivers, polluted with sewage, seems to me to be a disgrace to a civilised country and a reflection on the competency of engineers that they are unable to devise means for utilising what should be a valuable means of fertilisation, instead of allowing it to remain a disgusting and dangerous nuisance. In the matter of warming and ventilating much also remains to be done. We frequently read accounts of elaborate arrangements for the ventilation of some large building which are to result in perfection, but which, when put to the test, prove an utter failure; draughts exist in all directions, and the places are alternately too hot or too cold. I do not wish to make comparisons, or to point to instances of success or failure, but it would be easy to do so. As regards our private dwellings, the discomforts of defective warming and ventilating are still more apparent. It is seldom found possible to maintain an ordinary room at an even temperature; elaborate means are sometimes provided for the exit of foul air, but, beyond the cracks in doors or windows, no provision is made for a supply of fresh air, the natural result being "down draughts" by ventilators and chimneys through which the vitiated air should be passing away.

Then as to drainage, although in the present day we are fully alive to the necessity of providing means for the quick and efficient removal of sewage and dirty water from our houses, and, although this is perhaps fairly well carried out in modern houses of the best class, yet it is rarely attended to in the great majority of dwellings. The drains are frequently laid

so as to afford lodgments for solids passing into them, and ventilating pipes, if they are provided, rather convey a supply of foul air from the drains into the house, than take it away, and, in the large majority of houses, the same water-cistern serves for the closet and for drinking purposes. These and many other evils have been pointed out from time to time by sanitary engineers, but the fault lies not so much with them as with the jerry builders, and apathetic house-occupiers intent only upon getting the most imposing looking house they can for their money, and it is to be feared that no radical and general improvement can be looked for until some legislative supervision is provided for enforcing a proper care in the sanitary arrangements of all houses. Elaborate and frequently unnecessary regulations are insisted upon with respect to many building details, the fees for their supervision being in many cases exorbitant, but the sanitary conditions are totally disregarded.

In connection with this branch of engineering, reference may be made to the pollution of the air in towns. The consideration of this belongs, perhaps, more to the chemist than to the engineer, but, so far as the abatement of smoke is concerned, the engineer may render valuable assistance. All who inhabit large towns in England have long complained of their polluted atmospheres, which have been accused of being the cause of much sickness and disease. Investigations made during the last few years seem, however, to raise some doubt as to the injurious effects to health attributed to smoke-laden atmospheres. Although, perhaps, not the smokiest place in the world, London is at least bad enough in this respect, yet it has one of the lowest death-rates of large towns. How much lower this death-rate could be reduced if a purer atmosphere could be obtained remains to be proved; but it should also be borne in mind that the visible impurities are not the only ones which exist, and they are, perhaps, the least injurious. The products of combustion are largely composed of carbonic acid, carbonic oxide, sulphurous acid, and other invisible but noxious gases, which would still exist even if the visible smoke could be entirely prevented. Dr. W. J. Russell, Chemical Lecturer at St. Bartholomew's Hospital Medical School, has recently made a series of experiments on this subject, which furnish some interesting information, although they do not point to any remedy for the existing state of affairs. Dr. Russell collected and analysed samples of rain at three points in London—in the City, at Hackney, and in the north-west district. That collected in the City always had particles of soot floating in it, and, as a

rule, contained twice as much chlorides and sulphides as that collected at the other places; and the proportions of these salts were, in the summer, nearly three times as much, and in the winter twice as much in the City as in the other places. Dr. Russell also found that London rain, carefully collected, is not acid, but if left exposed in an open vessel for a considerable time it became acid, owing to the washing of the soot present in the air; and he concludes that, if the soot can be got rid of, no acid would be found. This conclusion seems scarcely established at present, for acid impurities must be emitted into the air from combustion, and they must be liable to be absorbed by moisture and deposited as rain or dew on surrounding objects. Be this as it may, and whether a smoky atmosphere is or is not injurious to health, there can be no doubt that it is exceedingly unpleasant and also injurious to furniture, &c., and we should all welcome any expedient which would prevent or minimise the nuisance. Much was hoped for in this direction from the Smoke Abatement Exhibition, but, at least up to the present time, it seems to have been singularly barren of results. England being mainly dependent upon coal for fuel, both for manufacturing and domestic purposes, it may be expected that it is, and will probably remain one of the smokiest countries in the world, and considering the enormous coal consumption this is not to be wondered at. Mr. Lowthian Bell has stated that in the year 1882 the coal output in Great Britain amounted to 156,499,000 tons, of which total he gives the following as being the largest consumers:—

Iron and steel works	46,950,000 tons.
Domestic purposes	26,918,000 „
Steam-engines	18,936,000 „
Mining operations	10,485,000 „

From this it will be seen that, with the exception of iron and steelworks, which are carried on chiefly away from large towns, the largest consumption is for domestic purposes, and, as the combustion is probably more generally imperfect, and consequently more smoke is emitted from this source than from any other, it seems to be in this direction that reform is most urgently needed; it is also, perhaps, the most difficult one to effect it in. Smoke-consuming appliances for steam-boilers are plentiful enough, and it is surprising that their adoption is not more generally insisted upon. For domestic fires, however, I think the contrivance has yet to be invented which will provide a smokeless open fire to meet the wants and prejudices of the

average Englishman. Grates were exhibited at the Smoke Abatement Exhibition which professed to solve the difficulty, but they were, for the most part, dependent upon the use of smokeless fuel, and although perhaps fairly efficient so far as concerned their heating power, they did not give the cheerful blazing fire dear to so many of us. It has been proposed to kindle our fires from the top, so that the smoke from the lower portions should pass into and be consumed by the incandescent fuel; but any one who has tried this will have found what a long time is required to obtain a satisfactory fire, and how difficult it is to maintain it.

The direction in which there appears to be most to hope for diminishing the smoke nuisance from domestic fires is in the more general use of gaseous fuel or coke. The use of coal gas for cooking and heating purposes is extending very much; for cooking it is undoubtedly more economical than coal if intelligently used, and even for heating purposes it may in most cases be satisfactorily applied. The practice of breaking coke into small pieces for sale is also rapidly gaining ground, and its use is consequently largely increasing. Coke, as removed from gas retorts, is in too large pieces for burning freely in an open fireplace, but if broken into small pieces, it burns much more freely and produces an economical and cheerful fire.

The development of electrical science, by its application to illuminating purposes, and its utilisation in various other ways, is perhaps the most remarkable event of the present century. Any one who had asserted fifty or sixty years ago that it would be possible to communicate in a few seconds with the most distant parts of the world, would have been regarded as a visionary or a lunatic, yet this, and more, has come to pass in our own generation by means of electricity. To me this appears the most wonderful application of science to the every-day uses of man; whether it is the most useful of the discoveries of the present age, may, perhaps, be open to doubt. We are able now to communicate with the most distant places in time that may be reckoned by minutes, where, before the introduction of telegraphy, months or almost years were required. This has naturally entirely changed mercantile operations with such places, and there are many who bewail the change, and would be glad to go back to the old style of business, if it were possible; but, however this may be, electricity has long since become a recognised and important branch of engineering, and its further development for electric lighting has added largely to its importance. At the present time electric lighting is somewhat under a cloud, in consequence, mainly, of the reckless and unprincipled speculations of inventors and company-

mongers, but there can be no doubt that a large field exists for its use. Whether it will be able to compete with gas, oil, or other illuminants for general lighting, seems as doubtful now as it was five or six years ago, when its virtues and advantages were sung as being the "light of the future," which it still remains. But, apart from the question of cost, there is no doubt that the electric light can be advantageously applied in many cases where other lighting would be inefficient or impossible; and, when the speculative mania has fully subsided, and electric light companies are content to cultivate a steady business, without attempting to illuminate the whole world at once, they may expect to succeed, and will be better able to judge to what extent it can be used. My own opinion is that it will never supersede gas, my experience being that, wherever it is introduced, the demand for gas is increased.

Those interested in electric lighting complain that the Act of 1882 imposes such onerous conditions upon companies desirous of establishing lighting centres that it is impossible for them to succeed, but a leading newspaper has very justly pointed out that in other countries, where this Act does not apply, electric lighting is still not flourishing. Attempts have been made to introduce it into India, where its freedom from heat might be considered a great advantage, and where other illuminants are more costly than here, but, so far, little or nothing has been done with it there. In certain parts of New York it is applied to street and domestic lighting, but we hear very little of how it is appreciated, or how it pays to supply it. In a paper recently read by Mr. Preece at the Society of Arts, some interesting details were given of the electric lighting by the Edison Company from a central station in New York, which is perhaps the largest example as yet of house and street lighting. At the time of Mr. Preece's visit there were 587 consumers, with 12,764 lamps, served night and day, the price charged being based upon a calculation of what gas at 7*s.* 9*d.* per 1000 cubic feet would cost for a similar amount of light; but Mr. Preece admits that this charge appeared too low, although he was informed that it yielded a profit of 3 per cent. upon the capital employed. No details were, however, given of how this profit was arrived at, and Mr. Preece considered that sufficient provision was not made for depreciation and maintenance. His opinion was that it would pay to supply the light in England at one halfpenny per glow-lamp per hour; but this has to be proved, and even then it would be more than twice the cost of gas, at all events in England. Except where it is employed for special purposes, or as an advertisement, it has been, in most cases, abandoned after a trial. Even the Edison Company found it necessary to give

up the lighting on the Holborn Viaduct, and the longest trial of all, that on the Thames Embankment, has also come to an end.

I do not wish to contend that electric lighting is a failure, for, as I have already said, it may in many instances be applied most advantageously: the arc lights for lighting large spaces brilliantly, and the incandescent lamps for large passenger ships, as well as for many other purposes. I believe the chief cause of its not being already in more general use is the unprincipled speculation which occurred at its introduction.

Perhaps the most extensive and successful applications of electric lighting in this country, which many of us had opportunities of seeing, were at the Fisheries and Health Exhibitions of the two past years. These gave good proofs of its adaptability for efficiently lighting large spaces, but we have as yet no detailed information as to its cost, although it is stated that upwards of 1300 indicated horse-power was employed with the engines for generating the electricity, and that 1180 tons of coal were consumed during the last Health Exhibition. There were over 5000 incandescent lamps and 334 arc lights employed, the illuminating power being estimated as equal to 285,850 candles.

It is not only in its applications to lighting that electrical science has made such great advances during the past few years but also in its older form for telegraphic purposes vast improvements have been introduced, by means of which the sending and receiving of messages have been greatly expedited. At the Electrical Exhibition, held at the Crystal Palace in 1882, the Post Office authorities exhibited a very interesting collection of instruments, some dating from the introduction of electric telegraphy, and others showing the numerous improvements introduced up to the time of the Exhibition. With the older forms of instruments and batteries the sending of a message was a comparatively slow process, while with modern appliances it is possible to despatch over 300 words per minute; and it was recently stated that a Mr. W. A. Legge, of Canada, had devised a means by which 3000 words per minute could be transmitted, his system being in successful operation between New York and Chicago.

In making these remarks this evening I have endeavoured to point out some few of the comparatively modern branches of engineering which may be expected to claim the attention of present and future engineers. It would not be difficult to mention many others, but they are doubtless familiar to all present, and I am afraid I have only been going over old ground which has already been more ably trodden by others. I will not,

therefore, detain you longer, but will conclude by asking you all to assist the Society and its Presidents, by introducing new members, by contributing papers, and by your presence at the meetings. I would also tender you my best thanks for the kind and patient hearing you have accorded me this evening.

March 2nd, 1885.

CHARLES GANDON, PRESIDENT, IN THE CHAIR.

AMERICAN ENGINEERING ENTERPRISE.

BY ARTHUR RIGG, PAST PRESIDENT.

IT is well known that the British Association for the Advancement of Science paid a visit to Montreal in the autumn of 1884, and many of its members took that opportunity for visiting places of interest in Canada and the United States, either for purposes of study or pleasure, or a happy combination of both. Some have gone so far as to say there is nothing to be learned or observed in that wide and boundless dominion, which to our unceasing satisfaction is in the possession of the Anglo-Saxon race, and not under the control of any foreign nation. To suppose that men of the most energetic race on earth could possibly develop the resources of a new country, abounding with every potentiality of wealth, without doing anything a traveller from their ancestral home may not see and study with advantage, is to confess a want of observation on the part of the visitor, an utter blindness, indeed, that carries contradiction convincing and complete to any statement so absurd. Indeed, so far is a contrary view the fact, that one might petrify the whole country as it now stands, and then spend the length of a long lifetime without exhausting its boundless subjects of interest, or, indeed, dipping very far below the surface of what we see. No short flying visit can possibly give enough time or opportunity for any single exhaustive study, so it needs little or no apology for bringing before my fellow engineers some desultory remarks upon a few of the many interests which gather around the western continent; and also it seems wiser to deal generally with some of these rather than attempt too much attention only to a few. Such a course seems best calculated to bring both writer and hearer into the unison of a rapid and somewhat imperfect series of disconnected observations, to awaken a wider range of interests, and very possibly serve as some help to those who may pursue the same line of travel

hereafter. Compared with the more familiar excursions to foreign countries, those weary rounds pursued by ordinary tourists, the advantages of travelling in Canada and the United States are enormous. The English language everywhere prevails; our literature is studied in the long dreary winters with a zest and industry hardly suspected at home; the names of our best writers are familiar to the many, and are not restricted, as here, to the cultivated few; and with these advantages there prevails an all-abounding intelligence—a vast community of interests among all classes of the people. This also tends to soften the asperities of those class distinctions which are quite as strong in America as here, and the necessity for intercourse during long journeys over vast stretches of desert country leads to the formation of new, pleasant acquaintances, and becomes a bond of social union which the peculiar railway arrangements do much to facilitate. And none who have had even a short acquaintance with the country can fail to be struck with the innate courtesy and good nature of the born American, particularly of the West, for in that respect it stands in most refreshing contrast to what we find in the manufacturing districts of England, or in their own eastern cities, overrun, as they are, with immigrants—not always of the best class—from Europe.

Judging from the experiences of a journey which extended from Montreal to Philadelphia, from Washington to Wyoming, from Montana to the Great Salt Lake, and thence viâ Denver and Leadville through Toronto and New York, past the eastern cities of Providence, Boston, and Lowell, and thus through every portion of the Northern States and Eastern Canada, one would recommend no greater treat or pleasanter travel to an Englishman than to go over the same ground, and mix with the delightful society of his fellow-countrymen across the sea. He may be sure of one thing, that they will be only too pleased to give him a hearty welcome. They will be proud to reciprocate his interest in their affairs; and there is nothing he may ever wish to see for which unbounded facilities will not be freely placed at his disposal. Even among the wild cowboys of the uncultivated West, amidst the dreary grandeurs of the Yellowstone, or over the barren hills of Colorado, he will meet with as hearty a welcome, though sometimes accompanied by a rough courtesy, as anywhere else in the world; and curiously enough, the deepest interest of the people seems aroused, as they listen while their visitor tells some news of "the old country," which is the affectionate term invariably used to describe their fathers' distant home.

Steamboats.

Coming over the sea, familiar with the general English types of steamers, perhaps the first things that strike a visitor in approaching New York are the enormous ferry boats and river steamers, which ply without a moment's cessation throughout the year. These boats run between New York and the adjacent shores, or down the river to health resorts in the immediate vicinity. Their peculiar beam engines, and double tier of decks, give a somewhat uncouth appearance, judged by eyes accustomed to the more symmetrical lines of our own river steamers. But yet a little examination shows how admirably these vessels are suited for their intended purposes; and some of them plying to Providence, or those of the more fashionable "Fall River Line," are veritable floating palaces, provided with engines of enormous dimensions. These engines have only a single cylinder, that of the *Rhode Island* being 90 inches diameter and 14 feet stroke, driven by 30 lb. steam pressure and making nineteen revolutions per minute. The Fall River steamer, the *Pilgrim*, has a cylinder 110 inches diameter, with 14 feet stroke. Its paddles are 41 feet diameter, and paddle shaft 26 inches. No difficulty whatever seems to be experienced in the management, starting, or reversing of these powerful engines, and the vessels they control may be seen threading amongst the crowded shipping with the utmost facility; and even in the dangerous "Hell Gate," now brilliantly illuminated by electric light, they are steered with a skill as surprising as it is completely successful.

Railways.

Immediately on landing, the chances are that we become acquainted with the peculiar railway arrangements of America. Long heavy cars, open from end to end, and supported by bogie carriages, have been often described. All are much over-heated in winter, by a stove in each car, with a range of hot-water pipes throughout its length, and to judge from the draughts caused by opening the hinder door, to say nothing of the forward door, one only shudders at the reduction in temperature which would occur by opening all the doors in an English carriage holding the same number of passengers when the thermometer is standing 20° below zero! At the larger railway stations or depôts, we do not see raised platforms, nor are the passengers obliged to keep upon any one spot; but are allowed to move freely over the boarded floors between the rails, and the loud bell, with which every locomotive is pro-

vided, gives warning of its approach as it moves slowly through the crowded stations. On all these locomotives there is a spark arrester, formerly constituting an enlargement of the chimney, but now generally constructed as a forward prolongation of the boiler. Nevertheless, fires are not unfrequently caused by sparks which escape, notwithstanding all precautions, for the draught is so vigorously maintained that showers of ashes pour in a continuous hail on the tops of the carriages, particularly when the train is slowly dragged up the steep gradients with which most American railways abound. Some of the eastern lines vie with those at home in the excellence of their railways and station arrangements. These maintain a high rate of speed for their passenger traffic—a speed easily reckoned, as there are thirty-two spaces between the telegraph poles for every mile; and one may sometimes count this distance run in seventy seconds, not unfrequently in sixty-five seconds; while higher unauthorised rates prevail at the indiscretion of reckless engine drivers. Accidents do occasionally happen, but as Miller's system of coupler buffer is now used on all the trains, it prevents that secondary disaster of the carriages telescoping, which used at one period to be the invariable sequel to a collision. Accidents are always pretty fully described in local newspapers, and though it may be somewhat reassuring to see trees being cut down and burnt, lest they might fall upon the line during winter storms, yet it is not so pleasant to pass a gang of men setting fire to the débris of a wrecked train as the speediest method for removing it out of their way.

Experiments upon different railway gauges have been carried out by various companies in the United States upon a scale of the utmost magnitude. They range from 6 feet to 2 feet, but mostly approximate closely to our standard of 4 feet 8½ inches. So long as differences fulfilled a purpose of preventing the rolling stock of one company being used by another, a sufficient answer was given to those who desired and pointed out the advantages of uniformity. But now that great trunk lines unite all parts of the country, this question has assumed greater importance—an importance accentuated by the events of the Southern war twenty-five years ago. At that period, owing to nearly all their railways possessing a uniform gauge of 5 feet, concentrations of the Confederate armies were effected with far greater facility than the numerous breaks of gauge allowed to the Northern hosts; and this fact shows what an enormous additional power is given to those who possess sensible railway facilities, and is denied to those who rely upon an imperfect system. Some of the Western railways have been laid with a

3-foot gauge, for economical reasons only. At the present time a complete and extensive system is exhibited by the Utah Northern Railway, which follows down the western slopes of the Rocky Mountain Divide or watershed; including also the Rio Grande Railway from the Great Salt Lake to Denver, with many connecting branches. Thus a traveller has ample opportunities for making any observations he thinks fit upon narrow-gauge passenger railways. These lines were constructed through vast stretches of uninhabited country and over difficult hilly regions; so it is only fair to those who decided their gauge, to suppose that none anticipated the rapid development which this new facility of communication was destined to promote.

Throughout the Eastern and Central States a standard of 4 feet 8½ inches is being adopted by all main lines; for the break of gauge has been found an evil of intolerable magnitude, so, with a broad and statesmanlike determination, some companies have already grappled with the difficulty, while others are preparing to do so, and thousands of miles have been altered by stoppages of two and three days' duration. It has been wisely considered that those permanent evils attendant upon existing confusion, would far outweigh the cost and temporary delay attendant upon an alteration of the gauge. Moreover, the extreme rapidity and ease with which long distances have been altered, and the small interference with traffic, shows that there is no real difficulty in making the change, and does great credit to the engineers who controlled what seemed so troublesome an enterprise. It is easy to allege the impossible, which is too often a mere cloak to cover want of pluck, or ignorance, yet one can only reflect with absolute astonishment upon the assertions of those engineers at home who would have us believe that a similar change could not be made in India. For a totally insufficient cause, that extensive country was originally saddled with a gauge of 5 feet 6 inches, too wide, as it has been proved, for any necessities, and it is a misfortune that the home gauge was not adopted when railways were first inaugurated there. Even now, it would seem better to face an inevitable problem of the future, to contemplate and copy the example of American engineers by preparing for an alteration all over the country to 4 feet 8½ inches at no distant period; meanwhile constructing all new railways at the narrower gauge, otherwise we shall permanently afflict India with the intolerable evils which will arise where a 5 feet 6 inch and a meter gauge come into continual contact. In Ceylon, at the present time, a discussion is progressing as to which of these two gauges should be adopted, as if in a separate island it mattered anything whether either the Indian or the standard

English gauge were adopted. To judge by American experience, and the conclusions of practical men, it would be far better to make the Ceylon gauge 4 feet $8\frac{1}{2}$ inches, for this would be best and cheapest in the end. It is with pleasure that we note how common sense has at last prevailed regarding the Suakin-Berber Railway, now to be made 4 feet $8\frac{1}{2}$ inches, instead of 1 metre, as first proposed.

Though it might suffice to say that a 3-foot gauge is obviously cheaper to construct than a wider one, yet those who advocate narrow gauges seem to consider their arguments reinforced by a statement that sharper curves can be constructed on narrower lines. But we all know that in turning a complete circle the circumference of the outer wheel travels further than the inner one, in the following proportion:—Travel of outer wheel = travel of inner wheel $+ 2\pi G$, where G = gauge of rails.

This objection to the ordinary gauge ignores the evils of a narrow base precluding the rapid passage of curves, and takes no notice of the patent fact that no difficulty is experienced in turning tramcars round curves far sharper than anything ever seen on narrow-gauge railways. Even regarded by the test of ephemeral cheapness—that common delusion which misleads the public and satisfies those who would leave all future to take care of itself—it may be remarked that in the level country, for 120 miles from Denver to Puebla, the two gauges run side by side, as on our Great Western Railway here. Therefore, this additional cost ought in all fairness to be charged against whatever saving there may have been effected by adopting a narrow gauge on the main line; and thus the imaginary great economy calculated upon by the original promoters must dwindle considerably.

It is an attractive and seemingly reasonable argument that when opening up a poor, extensive country, light tramways should be more suitable than railways; but much needless confusion is imported into all discussions on this matter, and incalculable loss inflicted upon districts ill able to bear it, by regarding the inches between rails as the only point at issue. Indeed, it is beyond controversy that the average dimensions of human beings should settle those of railway carriages, just as in more practical times than the present they settled the size of carts and carriages, the widths of their wheels apart, and the most convenient units of length. In these days, however, we are told to settle the gauge first and the carriages afterwards, and this inversion of the natural process leads to an absurdity we see on the Rio Grande Railroad, where the Pullman cars are 8 feet $1\frac{1}{2}$ inches wide, and the distance

between rails only 3 feet. With such a disproportionately small base, the carriages rock considerably while passing over rougher portions of the road, or while slowly crawling round quick curves at the edges of precipitous elevations. No wonder if a feeling of insecurity should drive away mere business travellers, so damaging the prosperity of the line, and, in some degree, interfering with a complete enjoyment of some of the finest scenery to be found on either continent.

But the advocates of narrow gauges have been untiring in their assurances that the break of gauge and its undoubted evils, which they are compelled to acknowledge, will vanish away when their system becomes universal; but let us see how these hopeful prognostications are realised in practice—for all of us will agree that a few facts are worth more than any quantity of imperfect theory. Quoting from an article of the *Denver Tribune-Republican* of October 6, 1884, we read—"Within the past half-dozen years a system of narrow-gauge roads, extending from the Gulf of Mexico to Lake Erie, has been gradually evolved out of numerous local and fragmentary lines that have from time to time proved themselves within reaching distance of each other. It was claimed two or three years ago that something startling would grow out of this new feature in railroading. It was contended that the narrow-gauge roads could not only be built for much less than the standard gauge, but that they could be operated at a smaller relative cost—that is, a given quantity of freight could be transported a given distance for a smaller total cost. The difficulty was the delay and expense of breaking bulk on through business. In order to partly obviate this, plans to put a narrow-gauge track into New York, and to connect all western narrow-gauge branches with this trunk, were matured some time ago, and were in process of execution when the panic threw many of the lines into the hands of receivers. The announcement that the longest of these lines connecting Toledo and St. Louis is to have its track changed to the standard gauge by the receiver and bondholders is full of significance. It is apparently a confession that narrow-gauge roads cannot compete successfully with the standard gauges on level ground, with the immense disadvantage against them that the standards are already in possession of the field, and have to be displaced by up-hill fighting." On reading facts like these, and the conclusions that have been come to by an eminently practical nation, one cannot avoid the reflection that it was an error of judgment in the first instance to construct 3-foot gauge lines, at any rate on level plains, for if it is now worth while to alter the gauge from 3 feet

to 4 feet 8½ inches to restore prosperity to a railway that does not pay, no further argument is required to prove that the standard gauge is the one that ought to have been adopted at first. All this forms a lesson which it were wise to consider and act upon rather than repeat such costly failures.

Turning now from criticism to the pleasanter task of admiration, we can see from the magnificent series of photographs taken by Mr. Jackson, of Denver, and displayed on these walls, how splendid is that line of scenery traversed by the Rio Grande Railroad. These pictures convey but a very faint appreciation of the grandeur of those stupendous passes through the Rocky Mountains of Utah and Colorado. Passing through the fertile vale of Utah, now decked with the autumn splendour of American forest scenery, we gradually rise and enter into a succession of deep cañons with rocky walls 3000 feet high, through the strange fantastic scenery of the Green River and across dreary deserts, until at last on the Marshall Pass an elevation of 10,854 feet brings us to the summit level of the railway. In one of the photographs before us, the zigzag of the railway across this elevated tableland may be seen winding its sinuous course over the summits of many hills, through long wooden snow sheds, past the edges of high and dangerous-looking precipices, and over wooden trestle bridges like the one 1850 feet above the river-level at the Toltec Tunnel, shown by one of the photographs. As the train twists and turns to every point of the compass, it gains glimpses of lovely scenes down many untrodden valleys, while the night gives passage through deserts and over the Marshall Pass through the Black Cañon of the Gunneston, until, nestled in a quiet secluded spot, the junction of Salida is reached. Here passengers for the rich mining districts of Leadville change cars, and after an excellent breakfast we start through the finest scenery which this region affords, the Grand Cañon of the Arkansas. The ever-courteous railway officials provide an observation car upon which their passengers can ride and gain a full uninterrupted view of endless scenes of surpassing beauty. The sunlit aspect of such cliffs as the Currecante Needle are succeeded by deep and gloomy valleys where its rays have never entered. The narrowed river accompanies our course with unceasing roar of its many rapids; and so narrow does the passage become at times that in one place, as shown in a photograph, no foundation could be found for one side of the railway bridge, and the engineers were reduced to the necessity of supporting it by two girders thrown across the Royal Gorge, and then suspending the unsupported corners of their bridge by tie rods from above, and thus over-

coming the difficulty. For 12 miles, there follows a succession of cañons where no exit would seem possible, until at last the train emerges into the level plains of Puebla, after passing along a most remarkable railway, justly considered by all who have enjoyed the sight of it as one great scenic route of the world.

It has sometimes been made a reproach to engineers, that an abnormal hideousness abounding in some of their productions, shows them incapable of appreciating the beautiful in nature or in art; but, although such an opinion may once have seemed justifiable, it can no longer be maintained, and no excuse is necessary for this digression from subjects coming more strictly within the scope of an engineering paper. The following table gives interesting particulars of all gradients through the Grand Cañon of the Arkansas, from Cañon City to the great mining camp of Leadville; and it will be seen that they range from 18 to 150 feet in a mile, and in the Marshall Pass the average grade for 14 miles is 217 feet to the mile. But a short branch siding from Hecla to Calumet, on the Rio Grande Railroad, surpasses this amount, and reaches the high total of 406 feet in the mile, or 1 in 13!

RIO GRANDE RAILROAD GRADIENTS FROM CAÑON CITY TO LEADVILLE, COLORADO.

Between Stations.	Average Grade per Mile.	Maximum Grade per Mile.	Maximum Ratio.
	Feet.	Feet.	1 in
Cañon City	9·8	18	293·3
Parkdale	43·7	73·9	70·5
Texas Creek	34·0	73·9	70·5
Howards	33·8	73·9	70·5
Mathrop	39·1	73·9	70·5
Buena Vista	52·5	73·9	70·5
Granite	70·0	73·7	71·6
Malta	76·8	75·0	70·4
Eilers	115·9	125·0	42·3
Brants	127·8	132·0	40·0
Laplata	112·6	125·0	42·3
Ow Junction	105·0	125·0	42·3
Leadville	145·0	150·0	35·2
Over Marshall Pass	211	217·0	24·3
Hecla to Calumet siding ..	..	{370·0 {406·0	14·3 13·0

The rapidity with which work is completed, both on Canadian and American railways, has often excited comment and surprise, and perhaps the most interesting example coming

under the writer's notice may be found in the new cantilever bridge over that deep gorge which receives the waters of Niagara. This bridge carries a double railway track, and connects the opposite shores of Canada and the States. It was made by the Central Bridge Works, Buffalo, and is 910 feet long, was commenced on April 15, 1883, and finished on December 1 in the same year, thus occupying only 230 days in construction.

American Locomotives.

So far as the American type of locomotive can be looked upon from an æsthetic point of view, it is a manifest failure. An engine enormously spread out, of a power less than many of our best examples, the design has become very familiar to English engineers from numerous published engravings. Although little or nothing has been accomplished in these engines to promote that beauty and neatness of finish so conspicuous in those of our best makers, yet the whole machine is admirably designed for its purpose, and all parts are easy of access. Its valves, instead of being placed on their sides as with us, are laid upon the top of the cylinder and driven by an overhanging weigh-shaft, a system of construction possessing several advantages. Much more than the length of an entire paper might be taken up with these engines and their peculiarities, but it may suffice to notice the most considerable departure some of them illustrate from our own practice. It is in the capacious furnace of the so-called "Wotton locomotives." Their furnace bars are raised above the driving wheels, and thus are only limited in width by that of the engine itself. In width they measure 8 feet, and in length 8 feet 6 inches or 9 feet, thus providing so much as 72 square feet fire-grate area. By the employment of so large an area for combustion, a very gentle blast suffices to produce the needful slow combustion, and such inferior qualities of coal as lignite can be used. This material contains as much as 20 per cent. of water, and the practical outcome of the whole system, measured by its economical results, may best be stated by giving the 1883 return of the Philadelphia and Reading railroad. For this year there is stated to have been a saving of $378,000 (78,432*l.*) to the credit of this class of locomotive. Moreover, the first of them started in 1877, and had then run nearly 184,000 miles without appreciable deterioration in either firebox or furnace bars, therefore one cannot but think experiments of this class, so original and successful, should receive very careful consideration from our own locomotive engineers.

Water Power.

In Canada, as also in the States, there are numerous large rivers, having falls of considerable elevation, so that the employment of water power has been a subject to which great attention has been devoted by American engineers. It happened that the era of great expansion in their commerical progress coincided with the time when turbines had just been developed in France, it was, therefore, most natural that these cheap and admirable motors should receive a due share of attention in America. So far back as 1844 the eminent hydraulic engineer of Lowell, Mr. James B. Francis, had examined and tested locally made turbines of an improved Fourneyron type, and thenceforward these motors became widely known and extensively used in America. Having had the advantage of inspecting turbines at Lowell under the guidance of Mr. Francis, and having also seen many others in different parts of the country either being erected or at work, the writer has enjoyed exceptional opportunities of forming an opinion upon those motors as compared with others of English manufacture. At Lowell there are to be found outward-flow turbines of the Fourneyron type, and also inward-flow turbines constructed upon principles similar to those adopted by Professor Thompson in his "Vortex" turbines. In the examples at Lowell both classes are designed by the most skilful hydraulic engineers in America, and constructed for giving the highest economical use of a scanty water supply, and not from considerations of first cost. Impartial tests of the greatest accuracy have been conducted by Mr. Francis, who is engineer of the Merrimack Water Power Company, and it is found that either inward or outward flow turbines give practically the same duty of about 80 to 82 per cent. This, therefore, may be regarded as the highest duty obtainable from the best finished turbines in regular work. We are, however, all well aware that there are numerous turbines extensively advertised, cheaply made, and really little else than rough castings bolted together, and for these exceptionally high duties are claimed. Such claims, however, have their origin in nothing more substantial than the imagination of sanguine manufacturers or the wishes of credulous buyers, and it is unfortunate that no reliable, impartially conducted tests are ever known to the public.

Fine examples of water power are exhibited by extensive sawmills at Ottawa, the capital of Canada, where work is carried on by electric light at night throughout the short summer, also in the well-designed and locally made machinery of the

Ottawa Waterworks Company. Along the banks of Niagara there are numerous mills being erected, while at St. Anthony's Falls, Minneapolis, the Mississippi River supplies what is estimated as 125,000 horse-power. The celebrated Pillsbury A mills are there driven by two turbines, each of 1200 horse-power, and their product is 25,000 bushels daily, by the roller system of milling. Large quantities of their best flour is exported to Scotland, and elsewhere all over the world. Any visitor is allowed to go all over these mills, accompanied by an intelligent guide, who will accept no gratuity for his services. From their level gravelled roof he can survey and admire a splendid prospect, where the great river winds its tortuous course, and only a few miles away stands the city of St. Paul, perhaps the most modern and most flourishing of rising cities in the American North-West. At Niagara, only 80 feet of its fall is utilised for driving turbines, and this seems about the limit that cast-iron wheels of large size can endure. The writer saw one turbine in which the first wheel had been broken to pieces by the current; a second stronger wheel was then working cracked; and a third, still stronger, was already provided for the next breakdown. Between these rough Niagara turbines and the well-made machinery at Lowell there is as great a difference as between similar classes of English work, and it is quite an error to suppose that American work must necessarily be cheaper than that of equal quality made in this country. Indeed, considering wages and cost of material, the thing is altogether impossible. Adequately to describe the vast industries of Lowell, the splendid engines by which their deficient water power is supplemented, the system of belt driving and method for extinguishing or escaping from fire, would require an entire evening devoted to the task. But that which most strikes an English visitor accustomed to the mill hands of Lancashire and Yorkshire is the superior appearance of a similar class at Lowell. This subject, however, has so recently been treated by Mr. J. S. Jeans, in a paper read before the Statistical Society, and by Mr. Pidgeon, in his elaborate essay "On Labour and Wages in America," published in the *Journal of the Society of Arts* of January 23, that it is unnecessary to do more than direct attention to it here; concluding, however, with the reflection that it would conduce greatly to the advantage of our own people if the high tone which still lingers around Lowell, in spite of an overwhelming immigration of French and Irish labour, could in some degree become acclimatised at home.

Mines and Mining.

The wealth of mineral deposits in the mountain areas of Canada and of the United States can hardly be exaggerated, and although disastrous results have followed the hopes of some sanguine speculators, yet very many fortunes have been made by successful operations in those regions. All along the Rocky Mountains range there are spots where abundant minerals of a profitable description are to be found; nearly all those who were early in the field have become prosperous, and such once rough mining camps as Butte, in Idaho, and Leadville, in Colorado, have developed into considerable towns. Helena, the capital of Montana, is actually built upon worked-out débris of a valuable gold mine, and in the mountains some twenty miles further north the writer had an opportunity of visiting the Montana gold mines, better known there as the "Drumlummon." It is situated at the upper end of a long gulch, in which every stone of the mountain stream seems to have been overturned in search of gold, and has recently been provided with new stamping machinery and powerful engines made in California. But as the usual process for extracting gold by amalgamation with mercury is followed, there is nothing special to notice.

But of more interest than any single place can possess is the crowded assembly of mining enterprises which centre around the lofty city of Leadville, in Colorado. Standing at an elevation of 10,150 feet above sea level, in an atmosphere of the utmost purity, having an average pressure of no more than ten pounds per square inch, this city has grown from five-and-twenty log cabins in 1878, to become the most extensive mining camp in the world. Probably no other spot can be named which has returned so large a profit to those who have settled there. Denver, the beautiful metropolis of Colorado, owes its prosperity mainly to Leadville, and though now the great "boom" has expended itself, and competition has lowered the miner's profits, yet a continuous flow of wealth steadily descends from the mountainous sides of the "continental divide," and the "city of the clouds" still pours its abounding riches on the plains below.

To its west are lofty snow-covered peaks of the Saguache Mountains, and to its east are the Mosquito Range, overlooking the city at elevations from 12,000 to 13,500 feet above sea level, while in a wide plateau between these hills run the quiet waters of the Arkansas River. Some ten miles away are the lovely Twin Lakes—a cool summer retreat from the sultry plains of Colorado; while, barring the road towards Leadville, stands a succession of considerable hills, which form the largest glacial moraine known to exist.

This country abounds not only with opportunities of sport for the hunter or profit to the adventurer, but also with scientific interest to the geologist and student of nature. The number and varieties of its ores renders the neighbourhood of Leadville one of especial interest to both classes, for there are concentrated many different minerals, generally scattered over far wider stretches of country. The prevailing and most important ore is argentiferous galena, with its secondary products, cerussite (carbonate of lead) and keragyrite (or chloride of silver). Lead is also found as anglesite (or sulphite) and pyrmorphite (or phosphate), and occasionally as oxide. Silver occurs frequently in the form of chloro-bromide, sometimes chloro-iodide sulphuret, or in a native state. Gold, zinc, arsenic, antimony, copper, bismuth, and iron are also found in Leadville, over a total area of ore-producing districts of about 225,000,000 square feet, and some of these ores are of extraordinary richness. For example, much sulphide ore found in "Seller's mine" has a thickness of 135 feet, and contains 200 ounces of silver to the ton. The writer spent two hours down this mine, and no sight can be more impressive than is seen in a walk along tunnels cut in every direction through dazzling masses of this vast mineral deposit. Smelting to a considerable extent is carried on at Leadville, and it has been noticed that owing to the high altitude lead compounds possess an unusual volatility. There are also large smelting works at Pueblo and Denver. So far as mining machinery is concerned, it is of the most primitive description. Their crushing machinery and stamps are similar to those used at home, and in steam engines or pumping machinery there is nothing worthy of special notice.

General Remarks upon American Machinery.

It would be impossible within the time at our present disposal to name a thousandth part of the things that abound in every direction to interest an engineer. Chicago, with its great elevators for storing grain, and its long rope-driven tramways, or the vast manufacturing industries of Lowell, would each repay weeks of study. Even a description of the works of Mr. Corliss, at Providence, might be expanded into a large volume. But apart from these things, which can be seen at any time, there were last year several interesting exhibitions of mechanical appliances—one at New York, two at Boston, and one at Denver, besides a superb show of electrical machinery at Philadelphia. To see the marble streets of that splendid city, light as day during the sultry nights, while an unceasing tinkling of tram bells went on for 168 hours every week without a moment's

pause. To see the crowds that thronged its busy avenues, and the numbers that lined its wharves or filled its ferry boats, the city seemed a very centre of life and unresting activity. Then it contains extensive engineering establishments, such as the Baldwin Locomotive Works, or Messrs. Seller's well-known tool manufactory; and the Southworks Works there is the original home from whence came high-speed engines.

It is most noticeable how much better all electric lighting is managed in America than here: one never sees those utter failures which so many companies have had to deplore, due probably to their interests being more absorbed with shares than science. Even in far-off Helena and at the Salt Lake city there are fine illustrations of electric lighting, while the brilliant crown that sheds a lovely light from the dome of the Capitol at Washington, seems an emblem of the glory of science at the feet of liberty. But the attractive subject of electricity would lead us far away from present objects, and it will be well to pay some little attention to another very important subject, that of the general

Design of Machinery.

The direct adaptation of tools to their intended purpose is very noticeable in all American machinery. In their planing machines, for example, everything is done to facilitate the attendant's labours by numerous little devices. The handles are arranged all ready for his use; and, as the table runs quickly back, its catch strikes against an elastic lever, and so moves the narrow belt with the utmost quietness and only about half the distance needed for an English machine. Then this action puts a friction pall into gear, and it deliberately advances the tool for another cut. The driving pulleys of these machines are ranged along the side, so they need not be placed across the line of main shafting as with ours, and, altogether, this one example might serve as text for a long dissertation upon the art of intelligent design, more particularly as contrasted with the clumsy planing machines which satisfy people here. Indeed, at one works the proprietor showed the writer an American machine for a different purpose, that was working well and with the utmost silence; while, not far away, was another doing corresponding work, and bearing the name of a large firm in this country. This latter was creating a deafening noise, and seemed as if concentrating its energies upon self-destruction every few minutes. A barbarous design, most appropriately named by its owner, as we left it, "Brute Force and Ignorance."

One cannot fail to notice that in setting out manufacturing

establishments of the best class in America, the object kept steadily in view is the need of cheap production under the disadvantage of expensive labour; and to this end the original first cost of machinery is considered of far less importance than any diminution of its productiveness, for that would be a continual drain upon profits. Settling the commercial aspects of any manufacturing concern may not lie strictly within the province of an engineer, but it ought to receive from him an amount of attention equal to its importance. That point where interest on first cost balances annual expenditure can be determined by very simple calculations, for if we assume capital all to be borrowed, and the machinery constantly in full work for fifty hours a week; and further, that a return of 10 per cent. per annum just covers interest, repairs, and depreciation, then it follows that unless an investment gives more than 10 per cent. it is not worth making. All excess over such interest becomes clear profit, and is frequently found enough to justify an opinion that no investment yields so high a return as first-rate machinery fully employed; and this is further illustrated by the old Lancashire saying that it is always worth investing 1000*l.* to save the annual cost of one man's labour.

Those who commence doing everything which imperfect knowledge considers cheap are little aware how wide-spreading are the consequences of such an opinion being entertained by themselves and communicated to their workpeople. That idea not only saps the foundations of permanent success, but also poisons the springs of all honest dealing. It acts by the force of an evil example, and constantly depreciates the quality of manufactures. Many of our goods are already nearly driven out of foreign markets in spite of our immeasurable advantages, and are being replaced by the productions of America and foreign countries. If there is much to see and admire in Canada and the United States, there is nothing more worthy of imitation than the system which prevails there to so large an extent, of having the best of everything, whatever it may seem to cost—a system which ensures prosperity to trade, self-respect to the manufacturer, and one that is consonant not only with the sound principles of political economy, but also with ordinary common sense. Some people seem imbued with an idea that anything said in praise of either American or of foreign workmanship involves an unpatriotic depreciation of what we produce at home. This is a very narrow view of things, for without having any sympathy with that cosmopolitan philanthropy which exalts every country at the expense of our own, it is plain that we can never indulge a generous

ambition, nor aspire to lead the van of progress, if we shut our eyes wilfully to what goes on in the world around.

There are no countries from which we can more fairly take example than those whose original inhabitants came from this. America has been peopled by the more energetic of our own race, who now possess a country of marvellous internal resources. By the help of their laws, and to their enormous gain, new inventions are eagerly sought after, and talent meets great encouragement. There a man does not need to labour for many long years in perfecting an invention, taking the doubtful protection of those statutes of limitation called our Patent Laws, only at last to find his ideas appropriated by another: a pirate who takes undue advantage of the numerous pitfalls by which an inventor is encompassed. And for another reason, it is no wonder that foreign countries get ahead of us, when even their governments wisely encourage every new departure, every improvement on existing methods. With them there is little of that nervous timidity about anything out of the beaten track, and none of that provoking interference due to the conceited half-knowledge of those who have learnt enough engineering to meddle with and spoil what they cannot understand. Abroad, engineers are more fully trusted than here, and they are therefore more free to obey the sound maxims—Make first sure of those general principles you intend to apply; then trust them implicitly; and, finally, never be afraid to carry them out.

Discussion.

The President said that the meeting had heard from the author a very interesting and suggestive account of engineering progress in America, and although perhaps English engineers might think that they were quite as experienced as their American cousins, still there was much to learn from them in many respects, while on the other hand American engineers might have something to learn from English engineers. The beautiful water-colour drawings which ornamented the walls of the meeting hall were the work of a visitor, Mr. John Dixon, and perhaps that gentleman would kindly give the meeting some of his opinions and experiences of America.

Mr. John Dixon said that he had lately returned from the States, and had amused himself while there in making a few sketches of the striking scenery in the Colorado district and the Indian territory of the Rocky Mountains. He had naturally paid a considerable amount of attention to the various mechanical operations which were being conducted in America, and he must say that he was well rewarded for his trouble and expen-

diture. There was very much indeed to be learned there, turn where one would; and there were also examples of what one ought to avoid. One of the things which most struck him in the United States was the disastrous effect of protective legislation. In the town of Pueblo, in Colorado, there were large lead smelting and refining works, such as would naturally be met with in a mining district. He was surprised, however, to come across an enormous Bessemer steel plant which must have cost 200,000*l.*, and in which the rolling mills and blast furnace were standing idle. It did not appear, upon inquiry, that they had turned out more than ten or fifteen thousand tons of rails at the outside. Doubtless the works had been put up by their owners in the expectation that they would do well, but by the time they were in operation it was found that, though protection duties gave them an advantage of about 4*l.* a ton above English rails, yet the same protective system had raised the prices of fuel, stone, and of every material required, and labour in the manufacture, to such an extent that the margin they had been revelling in was gone. Probably the most successful period in American manufacture was the ten years which preceded the great war. At that time free trade existed and everything had flourished. On Lincoln's accession to office duties were put on almost everything on which it was possible to place them. The result was that in the Western States, although English makers could deliver rails at Denver at about 7*l.* or 8*l.* a ton, the railway constructors there had to pay 12*l.* a ton for them. Things have at last come almost to a dead lock; and some very great changes must be made, if American manufacture was to continue to hold its own. The Western States, rapidly as they were increasing in population, would certainly not permit a continuance of heavy import duties, which were imposed purely for the benefit of manufacturers in the Eastern States. It could not be expected that the residents in the States of Kansas, Colorado, and Nevada, to whom railways were essential to their existence, would be deprived of their benefits, or only obtain them at an enormously increased cost, simply to put the balance in the pockets of manufacturers in the Eastern States. This question had really been the backbone of the excitement during the recent election. If a change was brought about in this respect he believed that the United States would again become a very large customer for English manufactures. English manufacturers could certainly beat America in the heavier branches of trade, and equal them in almost everything The stories to the contrary were, according to his observations, simply nonsense. As to their unbounded natural resources, the Americans had the great plains of the prairies on which they were

raising vast herds of cattle, and they had Montana and Minnesota and many of the other States where they were producing enormous quantities of grain; but they could not go on growing grain off the same land without manuring it. Corn land and also the grazing prairies would in time cease to give the returns which the virgin soil had been yielding, and he believed that, when the reduction took place, there would be considerable change in the general policy of the States, and that America would become open again, as it had been in the past, as a vast market for English manufactures.

He had been struck with the bold way in which many of the railways were constructed. It must be remembered that they had no Board of Trade regulations, or anything of that kind to bother them and increase their outlay. The American engineers could erect a bridge of what strength they chose, and if it answered its purpose, well and good, or, if it broke down and caused an accident or a smash, there was very little said about it. Some of the structures were striking examples of reckless engineering, and he did not know that that was to be regarded as an unmitigated advantage. Altogether he thought that English railways with their standard gauge of 4 feet 8½ inches, were about as good as any country could desire. Of course there was a great deal to be said in favour of the Denver and Rio Grande Railway, which ran through some of the scenery which was depicted in the photographs and sketches on the wall. A railway through such gorges was under any circumstances enormously expensive, and every little saving was an object; but, considering how rapidly the country was opening out, he regretted the policy of narrow-gauge construction. It was only a question of a few years—some ten or fifteen—before the companies would certainly find out the desirability of converting the railways of the West to a uniform gauge.

One thing which must be noticed by everybody in a tour through the States was the reckless and wilful destruction of the American forests. In the Eastern States timber forests hardly existed now, and throughout New York, Ohio, Pennsylvania, and Virginia, the traveller saw but a few trees here and there which were of such dimensions that they could be called timber trees, and far beyond the Eastern provinces, where there had been magnificent forests on the slopes of the Rocky Mountains, the hand of destruction was at work. Sometimes the timber on the mountain side for a distance of six or eight miles would be utterly burnt down and destroyed, having been set on fire by the mining prospectors and through other causes, but nobody interfered. In some places a traveller might walk for miles simply on the fallen trees which were lying thickly together on

the ground. He suspected that before many years several States would have to import their timber. It was pitiful to see such wilful destruction going on broadcast all over the country. As a result, the climate suffers, the rainfall diminishes, and agriculture is retarded. On account of the striking beauty of the scenery and the instructive nature of the observations which might be made there, a visit to America was about as good an investment of time and money as any enterprising Englishman could possibly engage in.

Mr. Robert Gordon said that he had followed very much on the lines of Mr. Rigg, and he to a certain extent confirmed Mr. Rigg's views. He had visited American workshops, and was particularly struck with the harmony which existed between the workmen and the masters, and the care shown by the latter for the physical welfare of the men. He had seen machinery of a very high type. He agreed with Mr. Rigg in the general remarks which he had made about American engineering.

Mr. J. H. Cunningham said that he quite agreed with most of the statements which Mr. Rigg had made. He had spent six years in America, and he took an extremely favourable view of the engineering work of that country. Without being unpatriotic, he thought that English engineers might learn a great deal on many points from the Americans.

Mr. Edward Bates Dorsey (Member of the American Society of Civil Engineers, and Consulting Engineer to the American Exhibition, London, 1886) said that the American engineer laboured under special and serious difficulties, and had little opportunity to show either his ability or desire; therefore his work should not be criticised unless the circumstances of its construction were known. One great trouble was that American railway companies commenced operations which they wished to be proceeded with and completed in the shortest possible time, before they had procured the necessary capital, and the constructing engineer was being constantly pressed to do the work with the greatest economy and expedition. Moreover, a large number of American railways were built in districts where there was no other means of transportation than the railroad itself, which consequently was obliged to transport all its own materials used in construction, and often a large local freight in addition, which for financial reasons the companies could not refuse, though it was very inconvenient. The great object of pushing the railways through with such haste was to receive income from the traffic, instead of paying out interest during construction. At the present time there were about 128,000 miles of railways in operation in the United States, and over two-thirds of them were located in a country too sparsely populated

to support railways built on the expensive English system. The cheap American construction answered the purpose very well, and was much better than stage coaching over bad country roads. The average cost of American railways was about 8000*l.* per mile. The average cost of those in the United Kingdom was about 41,000*l.* per mile, or over five times as much. The Americans had not enough capital to have built the above mileage at the heavy English cost, consequently their mileage would have been considerably curtailed if it had been constructed at the heavier rate. The American railways generally pushed on as rapidly as possible, and the engineer had constantly to study, not necessarily the best, but the quickest and cheapest way of doing the work. In crossing depressions or streams where the English engineer would use embankments, viaducts, or bridges, the American engineer was apt to build a trestle-work made from rough timber. This could generally be made at one-third the cost of an embankment and in one-sixth of the time, and it formed a good and safe support for the rails. Its duration was from eight to twelve years. Later on, when the engineer had more time and money at his disposal, the temporary construction was replaced by embankments or iron bridges. The American engineer made every effort to get the road open and trains running, even if the work were not first class. After this was accomplished he improved it at his leisure as fast as the money at his disposal would permit. In fact, he laid the rails first, and then built the road. In one case over ten miles of 4 feet 8½ inches gauge track was laid in a single day on one line, without the help of other railways or even country roads; over five miles of track was often laid in one day under similar circumstances.

The Denver and Rio Grande Railway, which had been so well described, might be taken as a type of American railway construction. About eight or ten years ago some speculators looked at the map of the United States and proposed to build railways south and west of Denver, not because there was any traffic that required their construction, but for the simple reason, probably, that the map showed that there was room for them, and by the laws of chance something might turn up in the future that would make business for them. This was the origin of the Denver and Rio Grande and Denver and South Park Railways. For economical reasons they adopted the narrow or 3-foot gauge. The southern line pushed on about 200 miles to Alamosa, in New Mexico, and suspended work there for want of money. Its rival, the Denver and South Park Railway, got out of funds at a stone quarry 22 miles out. Both railways were alike, commencing and ending nowhere.

The discovery and rapid development of Leadville was a godsend to both of these railways. The laws of chance upon which the promoters relied had come to their rescue in the shape of from 500 to 1000 tons daily of lead ore and bullion from the mines, and return freight of mining material, supplies for from fifteen to twenty thousand people, and a very heavy passenger traffic. The terminus of each railway was about 100 miles from Leadville. The traffic was divided about equally between the two railways, which, owing to heavy local charges, yielded large profits. This gave them new financial life, and both roads commenced to push on to Leadville as fast as the finances would allow, working all the winter. Owing to the elevation of the Denver and South Park Railway from five to ten thousand feet above the sea, the winter work was very severe, as the snow was at times several feet deep. The embankments upon which the rails were laid were largely composed of snow and frozen earth; this enabled the trains to run in cold weather, but when thawing commenced there was much trouble. However, the object, which was to push ahead with the construction of the railway, was achieved without accident.

The gorge of the Arkansas, which they saw so beautifully pictured in the photographs hanging on the walls, had such abrupt roads that the railway could not be surveyed; in fact, the surveys were made after the road bed had been partially built: this was probably the only case on record of building a railway without surveys or levels having been previously made.

The American rolling stock, with the bogy truck under all cars and engines, was probably better adapted for work on bad road beds than the rigid type of engines and cars in use here.

The necessities of the Californian gold mines were the cause of great improvement in hydraulic engineering. The miners found that the sands and gravel contained gold in small quantities, and if that could only be extracted in a cheap manner, it could be profitably worked. After many experiments it was found that water projected under pressure against the auriferous bank was the cheapest and most effective way. The force of the water dug the material, the current transported it through troughs to the dumping ground, and the gold settled by gravity in cracks left intentionally in the bottom of the troughs or "sluices" as they called them. At first the operator used canvas hose for conveying water; after this he used lengths of stove-pipe, tying canvas over the joints and angles. Each step was an improvement on its predecessor, and supplied more water at greater pressure. This gave such good results that the canvas was discarded and a continuous riveted iron pipe

adopted. Some of these mining works were of great magnitude. The Spring Valley Mine at Cherokee, California, used daily about 40,000,000 gallons of water, which was brought to the mine from the Sierra Nevada mountains a distance of 65 miles, through canal, tunnel and pipe, and crossed the valleys of two rivers, the first with 600 feet, and the last with 887 feet vertical pressure. The pipe or inverted siphon in the latter was 13,000 feet long and 30 inches in diameter, and the thickness of iron varied according to pressure from $\frac{1}{12}$th to $\frac{3}{8}$th inch; the tensile strain in some cases exceeded 17,000 lb. per square inch. The pipe was doubly riveted in the longitudinal and singly riveted in the cross joints. This pipe was made from the ordinary iron of commerce. The superintendent had recently informed the speaker that the pipe was as good as when laid, and showed no sign of rust, the asphalte coating having proved a thorough protection. The pipe had been in constant use for fourteen years.

Virginia City, Nevada, was supplied by water brought from the Sierra Nevada by two wrought-iron pipes 15 miles long and $11\frac{1}{2}$ and 12 inches in diameter. In their course these pipes crossed Washoe Lake and Valley, where for over two miles the vertical pressure was 1720 feet, or 740 lb. per square inch. These had been in use for ten or twelve years, and were in a satisfactory condition at the present time.

San Francisco, California, had been supplied from the first almost entirely with water conveyed through wrought-iron riveted mains which aggregated 40 miles of pipe 30 inches in diameter, the thickness varying according to the pressure. No. 14 B.W.G. was the lightest. It had been in constant use for from twelve to eighteen years, and was all in good condition now, though part of it ran through a salt marsh.

A pipe 19 inches in diameter made of No. 16 B.W.G. iron, after being in use for fifteen years, had been taken apart and made into 12-inch pipe, and had been so used for twelve years. It was now in good condition, after having been in use for twenty-seven years.

The Spring Valley Water Company, which supplied the city of San Francisco with water, was now enlarging its water supply to meet an increased demand. It required for this extension many miles of pipe, all of which was made of wrought-iron riveted. The Risdon Ironworks of San Francisco contracted to make a part of the pipe, and in reference to this contract the able superintendent, Mr. Joseph Moore, wrote a few days before to the speaker (Mr. Dorsey) as follows:—

"We contracted to make about 25 miles of pipe, mostly 44 inches in diameter, very little 36 inches. Our contract was to make the pipe in the shop, lay it in the ditch, and rivet

it together continuously. We contracted to complete daily 200 feet within two weeks, 400 feet daily within three weeks, and 600 feet daily within four weeks after date of order, and to continue it at this rate until completed. We averaged for many days 850 feet daily, and could have easily completed 900 feet, or over a mile a week. The pipe was entirely buried in the ditch. All joints riveted hot in the ditch, and cold in the shop by hydraulic riveters."

The Spring Valley Water Company anticipated additional enlargement of its water supply, and would soon commence to construct another long pipe line, which was to be 5 feet in diameter. It would be put across the San José Valley and would have a vertical water pressure of 500 feet for 24 miles.

The continued use of this description of pipe by the Company, after thirty years' experience, spoke well for it, and was the strongest endorsement it could require.

The pipe after being made was dipped into a bath of asphaltum, coal-tar, and lime, at a temperature of 380° to 450°. This formed an indestructible coating or enamel, and thoroughly protected the pipe from rust. So far as their experience went they had not found that the coating was affected by age. After thirty years' use it seemed to be as good and as strong as when it was newly put on.

The pipes were made in the shops in lengths of 25 to 40 feet, according to the mode of conveyance to the place of use. They were laid in the ditch and riveted together, making a continuous pipe. There was no provision made for expansion or contraction from heat or cold, and no inconvenience resulted from this.

In the United States there were over a thousand miles of this description of pipe in daily use and giving satisfactory results. Many places now supplied with good water, would not have had any if they had depended on the old cast-iron pipes or expensive aqueducts. The use of this description of pipe would undoubtedly largely increase, now that its strength, reliability, and durability had been proved by actual working experience. He (Mr. Dorsey) would recommend that the pipe should be made of mild steel, as this would give, for about the same price, a stronger and more uniform material than the ordinary iron of commerce.

By the use of this description of pipe the Californian miner had been able to work his mine at a remarkably low cost. With plenty of water and from 150 to 400 feet vertical pressure and good grade to his sluices (say 3 to 5 per cent.), the earth could be dug or mined, transported and dumped at the dumping point from $\frac{1}{4}$ to 5 miles' distance, and most of the gold could be extracted at a total cost of from a 1*d.* to 2*d.* per square yard.

From this system of conveying water for long distances under heavy pressure, there were developed the pipe lines for conveying oil from the wells to the sea-coast, and the Worthington pump for pumping against the previously mentioned heavy pressure. Both of these were now in use for the purpose of conveying water from Suakim to the stations in the desert in the Soudan.

Before criticising or condemning the work of the American engineer, it was only fair to ascertain as far as possible the circumstances and conditions under which it was carried on, and then to estimate how much time and money would have been required to build the same length of road or work on the English system. With these facts in mind they should decide which system of construction should have been adopted from the beginning. Under the actual conditions the speaker felt sure that an impartial verdict would in most cases be given in favour of the cheaper and quicker-built American roads, and against the more slowly built and more costly English ones, although the latter would be at first much superior in construction.

Mr. Perry F. Nursey said that the graphic description given by the last speaker of the rapid way in which American railways were constructed disposed at once of a question which he had been intending to put to the author of the paper, as to how the change of gauge was accomplished so rapidly on the United States railways. He did not think that engineers would be able to get a similar operation carried out so quickly on the Indian railways which had been referred to by Mr. Rigg, although there was plenty of land there to work upon. Another point upon which he should like to make an observation was that of electric lighting, which, as the author stated, had progressed very rapidly in New York and some other States. This progress was mainly due to the expensiveness of gas. Hence the consequent development of electricity as a means of ordinary lighting. The only other point upon which he wished to remark was the English machine mentioned in the paper, and which had been named by its American proprietor "Brute Force and Ignorance." It was perhaps fair that the meeting should know who was the maker of this machine, for it was not in accordance with the usual character of English machines. He occasionally visited some of the leading engineering shops, and though he certainly saw a great deal of force it was not of a brutal character, nor was there as a rule any ignorance displayed in the designing of the machinery which developed it. It was just possible that the machine to which Mr. Rigg alluded was supplied by some inferior English maker, and had unfortunately got to be regarded as an example of English practice.

Mr. Bernays wished to give expression to the very great

satisfaction which he had no doubt every one had felt with himself at the excellent manner in which their late President, the author of the paper, had represented the Society in America, and endeavoured to benefit the Society during his trip to that country. The subject of the paper was a very large one, and it had been admirably treated. They had heard some very apposite remarks from Mr. Dixon, who evidently thought that America was the *El Dorado* of contractors because there was no Board of Trade to look after them. Still he did not know whether in the end that was an advantage. He thought that a certain amount of supervision by authority was always useful, even in such matters as those that had been mentioned that evening. Mr. Rigg, in the opening of his paper, had mentioned some very extraordinary machinery in steamboats, as, for example, a ferry boat the engine of which had a single cylinder of 110 inches in diameter, and 14 feet stroke, and the boat was said to thread the river easily amongst a number of other steamers without any accident. That was a very remarkable thing, and he should like to know how the American engineers managed it. In very small tug-boats in this country, we had to use disconnecting engines, so that the paddle-wheels could be worked separately. He should like to ask whether Mr. Rigg had made any observations of the machinery on the steamboats in question so that he could give some details about it. With regard to turbines, he had formerly had to make a great many designs and applications of them, and had erected some. He must say that he had always been very much struck by the way in which turbines were now frequently sold ready made, like steam engines or tools. He considered that a turbine could not be satisfactorily made without its dimensions being calculated for each individual case. He was very glad to see that Mr. Rigg had made such strong remarks with reference to some of the American turbines.

Mr. Charles Hawksley said that he had been very much interested in the subject of the water-pipes of which they had been told by the American engineer who had spoken. The highest pressure which he had known to be upon a 9-inch pipe in this country was 730 feet. In that case the pipes were of cast iron, and not wrought iron like the American pipes which had been described.

The President said that the paper was one which could not be expected to provoke a very large amount of what he might call objective discussion, because they must all feel that the author's remarks were very appropriate, and that there was little to be said against them. He had seen steamboats which had been constructed in America with engines that rather astonished his English notions. Such a steamer had a beam

thirty or forty feet above the deck, which went up and down with a most monotonous motion, and the vessel looked as if it might be a little top heavy. The river steamers were models of comfort, but they also had some most gigantic engines upon them. Whether such engines were right or wrong, he should not like to say. He was much struck with the author's remarks as to the varying gauges of the railways, having had some little experience in India of the difference of railway gauges, which had always seemed to him to be a mistake. He thought that it would be well, if it were possible, to have a uniform gauge all over the world. He cordially agreed with some of the remarks which had been made by Mr. Dixon as to the protective duties in America. He believed that they were a great drawback to the country, for wherever there were heavy protective import duties they formed an inducement to deception. Some people got their goods admitted free, while others had to pay, and he suspected that something of the kind took place in America. With regard to the rapidity with which the Americans constructed their railways, he understood Mr. Dorsey to say that they had laid down ten miles in a day. He wished that some of the American engineers could be sent out to the East, and work on the Suakim and Berber Railway; for he was afraid that the gentlemen who had gone out from England to make it would hardly get through the work at that rate.

Mr. Rigg, in reply, said that he was extremely obliged to the speakers for the interest which they had been kind enough to express in what he had had to say. With regard to the question of Free Trade and Protection, to which Mr. Dixon had referred, he had purposely omitted that subject from his paper. But he had nevertheless come to the conclusion that it would be a very great misfortune to this country when America gave up protection, because such a change would give American manufacturers cheap labour and materials, and so enable them to compete with English manufacturers all over the world. For this reason he would never desire to persuade them to give up protection. The reckless destruction of forests was something distressing, as Mr. Dixon had said. He had seen hundreds of square miles of dead forest with every leaf and blade of grass gone. There was nothing more melancholy than such reckless waste. It was a great pity that the protection of forests had not received some attention in past times, for in many districts the only fuel was wood. The upper parts of the trees were cut off, but no trouble was taken to remove the stumps and roots, and the hill-sides were often seen covered with these stumps and no new wood growing. He was very much interested with Mr. Dorsey's remarks about American railways. He had passed over wooden railway bridges which

had creaked and groaned with the weight of the train, and he had been thankful to get to the other side. He had seen bridges with barrels of water upon them all along the sides, a very prudent precaution in case of the bridge taking fire. America was a country where certainly a great deal was done in a very rough and ready way. In many cases wooden bridges were being replaced by iron ones; and at Minneapolis a stone viaduct had recently been built. This showed that when the railway companies had more money to spend, they were not behind England with regard to the character of their works. At Boston there was a new station, which was quite a model of what a station should be in all respects. But of course in the Eastern States things were naturally more finished than in the West. In a new country which was being settled by emigrants, it was impossible for the inhabitants to incur any superfluous expense in making railways.

He was very much struck with the thinness of the water-pipes which were used. If a little leakage took place it did not seem to matter much, as water was plentiful; and it was remarkable with what slight materials they constructed pipes which were to bear such considerable pressure.

With regard to the subject of electric lighting, there was no question that great attention had been paid to it in America, because of the dearness of gas, but the point was that it appeared to be carried out there with more general success than here. As to the steamboat engines, the dimensions were those which he had given in the paper, and the characteristics were such as the President had just described. He had been surprised to see the easy and admirable way in which steamers provided with a single cylinder were steered, stopped, started, and reversed. He had done his best to ascertain the secret of such working, and had discovered one thing, that the paddles were loaded so that the engine never remained standing on its dead centre.

As to the origin of our standard 4 feet 8½ inches railway gauge,* he believed that the reason for its adoption was that the tramways in the north of England, on which the first locomotives were made to run, were laid to that gauge to suit the carts of the country.

* A paper on the early history of Railway Gauge, by William Pole, F.R.S., was read at the Institution of Mechanical Engineers, April 1875.

April 13*th*, 1885.

CHARLES GANDON, President, in the Chair.

THE DISTRIBUTION OF ELECTRICAL ENERGY BY SECONDARY GENERATORS.

By J. Dixon Gibbs.

The remarkable results obtained during the last few years from the production of electrical energy and its application to lighting purposes as well as to the transmission of mechanical power, have naturally brought into prominence the great problem of the distribution of electricity. In a complete system of electrical distribution, it is necessary that electrical energy in all its forms should be at the disposal of individual householders, whatever the service they may require it to perform; that is to say, if light is desired, currents should be available at will for feeding every type of lamp, whether arc or incandescent. If mechanical power is required, motors should supply it; whilst currents suitable for electro-chemical purposes should be obtainable with equal facility. The distribution should be over a large area, central stations being preferably situated in the outskirts of towns at a distance from the area to be supplied. Where water power exists it should be utilised, or, if steam power is used, a site should be chosen in proximity with water, so as to secure the economy in fuel effected by the employment of condensing apparatus.

It is scarcely necessary to remark that nothing hitherto done in the way of street lighting or of lighting large establishments, such as theatres, hotels, and public buildings, by means of machinery on or near the premises, can be claimed to constitute a distribution of electrical energy. The same may be said of the transmission of a given force to a single point. This is not a distribution of mechanical power. Gas and water companies do not set up separate works for the supply of special consumers, but from central stations distribute to all consumers in conformity with their several requirements. In order to arrive at the results just described as necessary to a complete system of electrical distribution, the following conditions are essential:—

1. Every receiving apparatus must be supplied with its pro-

portion of electrical energy, so that it may act independently of the others and without affecting them.

2. The regulation must be automatic, instantaneous in its action, and require no attention.

3. The regulation must be of such a nature that the generating dynamo machine shall produce each moment the exact amount of electricity necessary to supply all the apparatus in action.

The chief difficulty in realising these conditions has been that the intensity and electromotive force of an electric current being always exactly determined, the uses to which the current can be put are necessarily limited to feeding apparatus of a given resistance and of an electrical capacity in harmony with the quantity of available electricity; from which it results that by means of a given current it is only possible to employ apparatus of consumption of identical construction, that is to say, connected together under certain conditions of resistance that must be maintained constant.

The author need not review the various systems, more or less ingenious, which have been invented during the last few years with the result, not of solving, but of going round the difficulty, for in the interesting lectures recently delivered by Professor Forbes, before the Royal Society, the mechanism of all these combinations has been ably explained. It seems, however, to have resulted from the facts adduced in these lectures:—

1. That the future of electrical distribution lies in the direction of the employment of currents of high potential and small quantity, requiring conductors of small diameter.

2. That the employment of an apparatus, by means of which the factors of the initial energy can be transformed to suit the requirements of each consumer, is essential to the solution of the problem which we are discussing this evening.

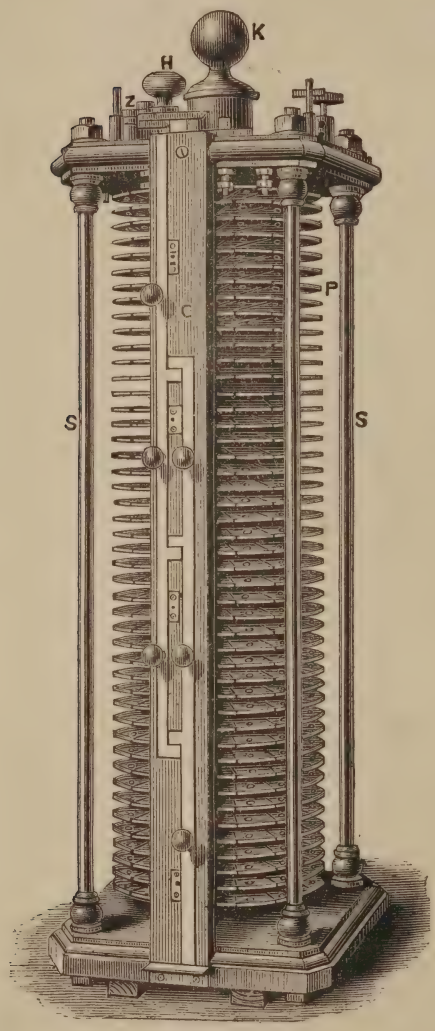
The secondary generators under review are such transformers. They are known as the Gaulard-Gibbs secondary generators. The phenomena of induction which have immortalised the name of Faraday are utilised in these instruments. Numerous predecessors have certainly conceived the idea of utilising secondary currents localised and of different kinds, but, coming later in this path of research, the inventors of the secondary generators have laboured under more propitious circumstances, because results already arrived at have enabled them to produce these phenomena under such conditions that their employment has been rendered absolutely practical and economical. This consideration certainly inspired them with the courage to pursue with perseverance those researches to which their predecessors had given but passing attention.

However this may be, the present inventors have regarded the employment of these phenomena from a purely industrial point of view. Their first thought, after having experimentally verified the actual transformation of primary electrical energy into electrical currents of different kinds, and capable of being applied to every practical purpose, was to make a careful analysis of the phenomena observed. They were thus able to determine the special conditions under which the primary and secondary circuits would yield the highest effective and most economical return for the energy expended; they arrived at the conclusion that the two circuits, inducing and induced, must have the same mass of metal and a position absolutely symmetrical with the common magnetic field. Since it is upon the determination of these conditions that the invention of the secondary generator is based, it may be interesting to know that these conditions, which are a *sine quâ non* of an economical return, have never been previously determined.

But it was not sufficient to determine philosophically what the industrial conditions should be, it was also necessary to realise them practically. The inventors accordingly constructed their apparatus with a sufficient number of spirals to produce the required practical electromotive force by means of a cable formed of an inducing circuit of low resistance surrounded parallelly to its axis by forty-eight wires composing the induced circuit, the sum of the sections of which was equal to the section of the inducing circuit. By means of this arrangement the theoretical conditions already alluded to were approximately fulfilled, since the mean distances of the induced circuits from the magnetic field were equal to the distance of the inducing circuit from the same magnetic field. Further, it was easy to group the extremities of the secondary wires so as to give to the factors E.I. of energy the different values required according to the work to be done. This apparatus served, during five consecutive months without interruption, to light with arc and incandescent lamps five stations of the Metropolitan Railway, one apparatus being placed at each station. The primary circuit in which they were placed was composed of a single wire 15 miles in length and one-eighth of an inch in diameter. This primary circuit was metallically closed throughout its entire length with the terminals of the dynamo machine at Edgware Road. The results as regards effective work formed the subject of a report by Dr. Hopkinson, the conclusions of which were perfectly satisfactory, and are too well known to require repetition.

The anticipations of an economical return having been thus

fulfilled, the next step was to seek the most simple and practical methods of applying economically the principle upon which the construction of the apparatus reposed. These researches led to the formation of the inducing and induced circuits by means of copper discs superposed and furnished with ear-pieces for the purpose of connecting them together. This arrangement, which allows of the juxtaposition of the two circuits, has also the advantage of permitting the employment of any insulating material that may be found to give the best results. The simplicity of this method of construction is obvious: the weight and size of the apparatus are remarkably small in relation to the work it is capable of performing.



The apparatus is identical in form with the generators exhibited at Turin. One column of the generator is shown in the margin. Between the supports S S, fixed on a wooden foot, the primary and secondary discs, P, are arranged as a column. The eyes, which serve to connect each two consecutive discs, are visible in the figure. Z to Z are the clamps for introducing the primary current; H is the handle for connecting or disconnecting the apparatus. The core of soft iron wire, K, serves for increasing or diminishing the production of the secondary current. The plates visible on the front bar, C, contain the connections for the secondary

currents, which may be derived at pleasure for arc or glow lights, or for both simultaneously.

It is worthy of remark that in this apparatus the actual resistances of the inducing and induced circuits are kept as low as possible, so as to render the work expended in the interior circuits very small in proportion to the work available in the exterior circuits. As an example, take the instrument we have before us: it is intended to supply in the exterior circuit an effective work of 750 Watts under the influence of a primary current of 12 ampères—the total resistance of its two circuits induced and inducing is three-tenths of an ohm, so that $12^2 \times \frac{3}{10}$ Watts represents the work absorbed by the apparatus, and consequently useless; thus the theoretical loss of energy resulting from the interposition of this apparatus is $\frac{43 \cdot 2}{750}$, or $5\frac{3}{4}$ per cent. Nevertheless, when the inventors announced an effective return of 90 per cent., many doubts were expressed in consequence of the unfavourable results hitherto obtained from researches in the same direction—these doubts were really testimonies to the novelty of the results—it remained only to demonstrate conclusively the truth of these results. The authority of an eminent electrician had been insufficient to carry conviction to every mind. An exceptional circumstance, however, enabled the inventors to determine definitely, without room for further question, the accuracy of their assertion.

In the month of January 1884 the Italian government offered a grand prize of 10,000 fr., to be competed for internationally, for the most important advance made in the transport of electrical energy to a distance, and invited other governments to name representatives who should constitute a jury for deciding the question. The Italian government was probably influenced in taking this step by the conviction that the industrial development of Italy would be largely aided by the prompt utilisation of the vast natural forces in which the country abounds. The jury was composed of:—M. Trescat, Membre de l'Institut de France, Honorary President; Professor Ferraris, Acting President; M. Wattmann, Rector of the University of Geneva: Professor Voit, of Munich; Professor Webber, of Zurich; Professor Roiti, of Florence, Member of the International Commission for the determination of the Ohm; Professor Kittler, of Darmstadt; Professor Cossa, of the School of Engineers at Turin; Professor Farini, of Milan, &c. Professors Voit and Kittler were the gentlemen deputed to take electrical measurements at the Vienna and Munich Electrical Exhibitions.

Practical experiments of the distribution of electrical energy by means of the secondary generators were made under conditions which M. Tresca, in the name of the international jury of the Turin Exhibition, communicated to the Académie des Sciences de Paris, in terms of which the author will read a translation. The original was published in the *Lumière Electrique* of October 18, 1884. It runs as follows:—"An International Electrical Exhibition is now being held at Turin, in connection with which an important prize is offered by the Italian government and the town. I am charged by my colleagues of the jury of this Exhibition to bring to the notice of the Académie the following facts:—Messrs. Gaulard and Gibbs have established at the Exhibition, the station of Lanzo, and the intermediate stations, a circuit whose length, including return, is 80 kilometres, by means of a bronze chrome wire 37 millimetres in diameter without covering. This wire carries an alternating current produced by a Siemens electro-dynamic machine of the 60 horse-power type, in such a way that the current can be simultaneously utilised for different modes of lighting, whether at the Exhibition, or at the Turin station, or at the Lanzo station, or at the intermediate stations, by its transformation at each point of the two factors constituting its energy by means of the secondary generators of the new type, shown by Messrs. Gaulard and Gibbs. On September 25 we verified the simultaneous regular working,

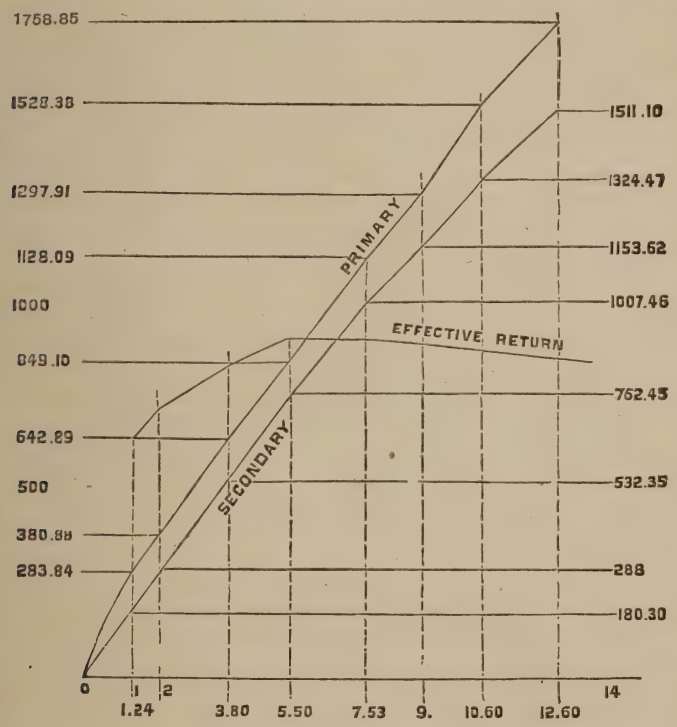
"1. At the Exhibition, of the following apparatus, which had to be necessarily supplied with very different potentials—nine Bernstein lamps, one sun lamp, one Siemens lamp, nine Swan lamps, and five other Bernstein lamps situated at a small distance.

"2. At the Turin Lanzo station, 10 kilometres away, thirty-four Edison lamps of sixteen candles, forty-eight of eight candles, and a Siemens arc lamp.

"On September 29 the experiments were still more conclusive, the system being extended to the Lanzo station, 40 kilometres distant, by the perfectly regular action of twenty-four Swan lamps of 100 volts. The numerous transformations required by the variety of these different methods of lighting are effected with accuracy, and, although we are not able to give the exact figures, it is perfectly demonstrated that the secondary generators may be considered, at all events within certain limits, as transformers giving a relatively large return of the energy of alternating currents. The actions of lighting and extinction are effected without any disturbance (of the other lights), and by means of simple commutators. The principal object of this communication is limited, however, to testifying to the complete success of a distribution of different modes

of lighting over an (effective) distance of 40 kilometres. The importance of the realised fact alone demands that it should be fixed by a precise date, but it should be borne in mind that we are not dealing here with the transport of mechanical power."

More than 300 Italian engineers and architects assembled for the 1884 congress, who had witnessed the experiments, passed a resolution of which the author will read a translation. "The fifth congress of Italian Engineers and Architects cannot ignore the great importance of the experiments now being made at Turin by means of the Gaulard and Gibbs' secondary generator, and, having examined the working of such a system of distribu-



tion, record the hope that the government, the corporations of towns, and manufacturers will patronise this system, and that the expectations which five months of trial on the Metropolitan Railway, the experiments at Turin, and the sound scientific conceptions upon which the system is based have raised in the field of science and industry, may thus be realised."

The measurements taken by means of the electrometre of

Mascart of the effective return of the secondary generators are shown by the curves on the accompanying diagram. In taking for abscissæ the resistances introduced in the secondary circuit, and for ordinates the primary and secondary work, it will be seen that the progression, at first increasing, arrives at its maximum between the resistances of 6 and 10 ohms, which are the resistances under which the apparatus works normally. But these measurements having been considered by some members of the jury not absolutely free from theoretical objections, a commission, composed of Professors Webber, Voit, Roiti, and Ferraris, was appointed by the jury to prepare a calorimeter, by means of which Professor Ferraris carried on his experiments during seven consecutive days, and arrived at the conclusions which formed the subject of a special report, which is very voluminous. The conclusions of this report are condensed in the table of which the following is a copy, and which gives an average practical return (column (N)) of 94 per cent. when the apparatus worked under the conditions for which they were constructed.

In this table are shown the theoretical and practical co-efficients of the return from a secondary generator coupled in tension, calculated in the following manner, for a series of resistances of the secondary circuit. In column R the values of the total resistances of the secondary circuit vary from 0·28 to 40·0 ohms. In column M are shown the theoretical values of the co-efficient of the total return. In column N are shown the values of the co-efficient of the exterior theoretical return, and in column (N) the values of the co-efficient of the exterior practical or effective return.

R	M	N	(N)	R	M	N	(N)
0·28	0·500	0·000	0·00	22	0·976	0·963	0·95
2	0·876	0·753	0·74	24	0·976	0·964	0·95
4	0·933	0·867	0·86	26	0·975	0·964	0·95
6	0·956	0·911	0·90	28	0·975	0·965	0·95
8	0·962	0·928	0·92	30	0·975	0·966	0·96
10	0·967	0·940	0·93	32	0·974	0·966	0·96
12	0·971	0·948	0·94	34	0·973	0·965	0·95
14	0·973	0·954	0·94	36	0·973	0·965	0·95
16	0·974	0·957	0·95	38	0·972	0·965	0·95
18	0·975	0·959	0·95	40	0·971	0·964	0·95
20	0·975	0·961	0·95				

Now that the secondary generator has been absolutely demonstrated to be a perfect transformer of the energy of alternating currents, it only remains to the author to examine whether the conditions under which these instruments act are in

perfect accord with the conditions laid down at the commencement of this paper for the solution of the problem. In order to thoroughly understand that this is so, let us suppose that we have to distribute 10,000 glow lamps, 200 arc lamps, and 200 mechanical horse-power in varying proportions, over a circuit 15 miles in length. The author adopts these figures because they represent somewhere about the average requirements of the future. With the aid of the secondary generators this distribution would be effected in the following manner :—

The initial electrical work would be produced by four alternating-current dynamo machines, of the Siemens model, for example, supplying 100 ampères and 3000 volts each. This work would be distributed over four distinct circuits, metallically closed with the terminals of each dynamo, and formed of a cable having a diameter of only one centimetre connected with the secondary generators, one of which would be placed in the house of every consumer. The form and size of these secondary generators would necessarily be proportioned to the quantity of work required of each one respectively. It may be remarked here that the secondary generators, fed by an electrical quantity which is constant, develop on the current which feeds them a counter electromotive force which is proportionate to the work they develop in their external or secondary circuits. From this it follows that the quantity or ampère value of the primary current must remain fixed, whatever may be the number of secondary generators to be fed, and that the electromotive force only of the primary current will vary according to the sum of the resistances set up by the number, more or less important, of the generators in action on the circuit. This result is automatically obtained by means of a regulator of intensity, which, placed in the primary circuit, acts upon the derivation of the exciting machine, by introducing variable resistances, so as to proportion the intensity of the magnetic field of the generating dynamo machine to the electromotive force which it must develop in order to overcome the resistance opposed by the secondary generators in action.

It is necessary to remember that the work developed by the secondary generators depends absolutely upon the number of spirals of which each is composed, and the form of energy developed depends on the manner of grouping these spirals. From this it follows that each consumer may, as it pleases him, put his apparatus in action, and cause it to produce the special form of energy he wishes to employ without troubling himself about his neighbours. The most absolute independence of each apparatus, and an automatic proportioning of the work produced to the work expended, permit the realisation by this

system of the essential conditions already indicated for enabling a distribution of every alternating form of electrical energy in currents resulting from the phenomena of induction, which produce always, and necessarily, the alternating form of current.

The old ideas, attributing special danger to the employment of alternating currents, have been ably corrected by Professor Forbes, Dr. Hopkinson, and others; but it is worthy of remark, that in an installation under the system the author is discussing —whatever may be the electromotive force of the primary current, which, it must be remembered, circulates always in a closed circuit—the difference of potential between the terminals of the secondary generators will never be greater than that necessary for the lamps fed by them—that is to say 100 volts or 50 volts, as the case may be. Nothing, therefore, short of culpable carelessness could possibly give rise to a condition of things presenting any danger whatever to the public.

If consumers required electrical energy only for producing light, a solution brought to this point would be as complete as possible; but the applications of continuous currents are too numerous not to render their distribution also desirable, and that with the same facility which, it has been shown, attends the distribution of alternating currents.

It has been already pointed out that the condition *sine quâ non* of the practical and economical transport and distribution of electrical energy to a great distance is to give to the energy to be transported the form of small quantity and high tension, or electromotive force. But although the known types of alternating-current dynamos adapt themselves with the greatest facility to the production of currents of the highest electromotive force, this is, unfortunately, not the case in regard to the collection of continuous currents of a higher electromotive force than 2000 volts. On this account the inventors of the secondary generators sought and found a means of redressing the alternating currents produced by their secondary generators. These currents, it will be remembered, have already, by transformation, a low electromotive force, that is to say, they are in the form most readily utilisable. On November 16th last Professor Ferraris, President of the International Jury of the Turin Exhibition, witnessed the perfect redressing of a current produced by a secondary generator—this current having 16,000 changes of direction per minute.

The instrument for redressing an alternating current is composed of several electro-magnets coupled in series and fixed on a cast-iron frame, a similar number of electro-magnets attached to a movable frame turning on its axis, a redressing commutator fixed on the same axis, having as many changes of polarity

as bobbins, and lastly of collectors receiving the currents. The alternating current enters by the fixed bobbins, traversing them in series; the point where the current leaves is attached to the brush which communicates with the commutator; the opposite pole communicates directly with the other brush. These brushes are so arranged that they can never come into contact with the same metallic pieces. If the apparatus is at rest, the movable electro-magnets are also traversed by the alternating currents; but as soon as the apparatus begins to work, the commutator inverts the poles of the movable electro-magnets. When the speed has reached the synchronism of the alternations, the current becomes continuous in the movable bobbins, and maintains the synchronism. It is necessary only to take a derivation on the collectors to have a continuous current.

This instrument has, then, the property of taking, under the influence of a very small alternating current, a speed which is synchronic with the changes of direction of the current which feeds it. Thus, then, until it has been found possible to do important work with continuous currents of high electromotive force, the secondary generators will enable the distribution of electrical energy in all its forms, whether alternating or direct, whether of high or low potential, over distances sufficiently great to enable the practical utilisation of natural forces. The value of the progress thus realised has been officially recognised in Italy by a grand prize of 10,000 francs.

Besides installations in Italy and elsewhere, there is one now in course of preparation, of which the central station is situated in New Bond Street, which will doubtless be studied with interest. This installation will consist of the distribution of more than 5000 lamps of various systems—the steam engines now being placed in position are of over 600 horse-power indicated, and have been manufactured by Messrs. Marshall and Company, of Gainsborough. The dynamos to be used are by Messrs. Siemens Brothers, and are the largest yet made by that firm; they have already been tested, and give most satisfactory results. An excavation of 6000 square feet has been made under the Grosvenor Gallery, and in this space the machinery is being placed.

It may be interesting to mention that, pending the laying down of the large engines, a temporary engine of 30 horse-power nominal is driving two Siemens W′ dynamos coupled in parallel, which give a current of 24 ampères and 800 volts. This current traverses sixteen secondary generators of 2 horse-power each, which supply currents for 300 glow lamps distributed in the library and club at the Grosvenor Gallery, and in two adjoining establishments in Bond Street. When the satis-

factory working of the permanent installation shall have been demonstrated, it is not unreasonable to expect that a wide extension of the application of electricity for the purpose of house-to-house lighting, upon the principle described by the author, will take place.

DISCUSSION.

The PRESIDENT said that he had no doubt that the arrangement which had been described was a very valuable and important one, for, as he understood the author, there was much difficulty in supplying electricity for various purposes and of different intensities from the same source, and the secondary generator, which had been described, was to overcome that difficulty.

Mr. GIBBS said that the President was quite right in supposing that one of the difficulties in the distribution of electrical energy was the supply of various apparatus having different resistances. That was one of the difficulties which had been overcome in the arrangement made by M. Gaulard and himself. In addition to that, they were able to transport electrical energy in the form of small quantity but high potential, so that those apparatus which required a large quantity of electricity could still be supplied, because, when the current arrived on the spot where it had to be utilised, it was passed through one of their apparatus and transformed from a current of small quantity into a current of large quantity, or of the quantity necessary for the work which it had to perform; and instead of having a high electromotive force, they had a low electromotive force. Formerly there had been a difficulty in transporting a current of sufficient quantity to do the work required of it. Hence the enormous leads which must be used upon any system which was fed direct from magneto machines.

Mr. MACKENZIE called attention to a small secondary generator exhibited on the table, and gave a detailed explanation of its structure and action. He then remarked that the central station at Bond Street, which had been mentioned in the last part of the paper, would be the first installation in England for a house-to-house supply on a really large scale. In the Bond Street installation, the Company (Sir Coutts Lindsay and Company, Limited) were working under such conditions that they could practically compete with gas. He had no doubt the experiment would succeed, and that a great future lay before the invention.

He explained that, when twenty-four or twenty-five lamps in a house were being supplied by a generator of this description, and some of them were turned out, the remaining lights became

brighter if the generator was left in its normal condition. Regulation could be effected, either by pulling up the core of the generator, or by cutting out part of a column so that the acting column should not be longer than was required to supply the remaining lamps. The latter method was adopted in these generators, and the length of acting column was accommodated to the number of lights burning, by means of a self-acting regulator attached to the lamp circuit. He did not, however, think that the apparatus was as perfect as it might be made.

The PRESIDENT asked how an arc lamp and a glow lamp could be burnt together.

Mr. MACKENZIE said that they were never burnt off one column. There must be a separate column for each type of lamp. The putting of resistance into the shunt circuit of the exciting machine, for the purpose of altering the current when lamps were turned out, was a very roundabout way of acting upon the primary current. It would be better probably to put the resistance into the exciting circuit direct, but this had not been done yet.

Some danger had been apprehended in connection with the use of electric lighting. The only danger which could arise from the use of the apparatus described in the paper, would be in the case of the wires in a building leaking, and a similar leak occurring some distance off. There would then be two secondaries in connection with the earth. If the primaries in action at the two houses got into connection with the secondaries, there would then be a very decided flow of current to the earth, which would be very dangerous to any person touching the wire; but this danger would not arise unless two secondaries became connected with the earth at one time.

The proposed installation in Bond Street would be carried overhead, but the cable would be carried upon seven strands of No. 16 steel wire, and connected with two double shackles, so that it would not have to carry any of its own weight.

Mr. W. B. ESSON said that he looked forward with great interest to the development of this system of distribution, and there were some points about the apparatus to which he would like to refer. The first thing which struck him was that the several columns of the generators were magnetically isolated from each other. If the field of force were mapped out, it would be found that the lines of force went right through the iron of the columns, and returned outside the columns in such a direction as to form complete magnetic curves. It had occurred to him that if the magnetic curves were completed through iron instead of through air, the coils of the generator being wound on a closed iron ring instead of isolated columns, there would be a large increase of the inductive effect, owing to

the great reduction of resistance in the magnetic circuit. Probably that effect would be ten times what it was by the present arrangement. Another point to which he would refer was that, as shown by the diagram, the electromotive force in the secondary circuit rose in proportion to the resistance, and that was exactly the condition of things that was wanted for working with a constant current. It therefore seemed that the apparatus was obviously the best which could be devised for working incandescent lights, or any other kind of lights in series. He believed it was quite possible to use satisfactorily incandescent lamps in series. The apparatus as constructed seemed admirably adapted for this method of lighting, for when all the lamps were turned out there was no electromotive force, the secondary being short-circuited; but as the lamps were lighted, the electromotive force rose proportionately to the number of lights.

Mr. Perry F. Nursey said it seemed to him that in the system before them they had a very elegant and practical development of Professor Faraday's beautiful experiments in connection with induced currents; and he believed that this was the first time the theory had been worked out to a practical issue. He had had the opportunity of seeing the first installation on the Metropolitan Railway. Its working was unquestionably most perfect. He traced the system throughout the whole circuit of fifteen miles and found the installations at the five different stations working most satisfactorily.

The question of danger had often been raised, and it had cropped up that evening. He had had a practical proof of the absence of danger in connection with this system. When he was examining one of the secondary generators, his ear came into contact with one of the metallic connections of the apparatus, and he felt a slight shock on his ear, but the effect went no farther than that. There were two questions which he believed electrical inventors would have yet to answer, with regard to the practical adaptation of electricity in house-to-house lighting. In the first place, could they supply ordinary consumers at a cost equivalent to, or only a trifle more than, the price paid for ordinary coal-gas illumination? The second was, could they persuade the ordinary British householder to remove his present fittings and replace them with electrical fittings at his own cost? If they could do this and could assure him that he would not have to pay more, or not much more, than he at present paid for ordinary gas, then electrical contractors might hope for success.

Mr. Olrick said that M. Gaulard and Mr. Gibbs had evidently produced something which was very practical. He was acquainted with one place, at all events, in England, where it was expected to have an extremely beneficial result, and to

probably save one company from insolvency in so far that they would thus be able to convey power from a place where it was cheap to another place where it was wanted. The chief cost heretofore in large electric installations had been in the conductors, and this had prevented their being carried out. He thought that they might take as conclusive the opinion of such authorities as Dr. Hopkinson as to the efficiency of the apparatus. It seemed to him that the secondary generator held the same relation to electric currents that a pressure reducing valve did to high-pressure steam. Under such circumstances it must be of very great use in the transformation of electrical energy.

He was aware that many months ago some enthusiastic people suggested that the falls of Niagara should be taken as a source of power, and that a current of low potential should be taken to different towns, by means of cables which were to be of copper, and were estimated to be of the size of a man's body. Those would cost a great deal. With the present apparatus he believed that it would be absolutely practicable to take currents to a very long distance. Mr. Nursey had interposed his ear in the current, but he (Mr. Olrick) supposed that it was the secondary current and not the primary, and he thought that if Mr. Nursey's ear could withstand the 700,000 volts, or less, that was employed, it would be in very great demand as a high class non-conductor. However, there was no doubt that the power could be dealt with so as not to be dangerous, although he should not like to experiment with anything above 200 volts. He believed that M. Gaulard had solved the very difficult problem of taking currents to a long distance economically. Mr. Edison had tried to do this in New York without success, and the financial failure of his installation there, had been due almost entirely to the enormous cost of the conductors.

Professor George Forbes said that he had examined every attempt at the supply of electricity which had been introduced both into this country and America, so far as he had been able to do so, and notably that of Mr. Edison of New York. In no single system were there the elements of success at the present time. There was not the slightest doubt that any large system of distribution like that at Mr. Edison's central stations in New York and elsewhere, must lead to commercial failure. In a paper which he read last year before the Society of Telegraph Engineers and Electricians, he pointed out that it was quite manifest that the size of the conductors which would be required in any large installation would reduce the whole arrangement *ad absurdum*. According to the law of Sir William Thomson the copper conductors which would be required for an installation of 100,000 Edison lamps in the most economical

arrangement—that is to say, one which would not waste too much energy in the conductors themselves—would have to be of about the thickness of a man's body. In questions of the distribution of electricity he always liked to work with an analogy taken from hydraulics. The parallel system supply was exactly analogous to the high-pressure system of water which was spread throughout London at the present time. That is to say, there were main conductors which carried the water or the electricity, and these supplied a number of apparatus for using the forces—turbines or whatever they might be—each of them being connected with the main conductor. There was another system which also had a hydraulic analogy. One might use a much higher pressure of water, and pass the water supplied by the main conductors through the turbines, and thence pass it, not into the open air, but into a second set of pipes at half the pressure of the first, and from them lead the water again through a new set of turbines before it escapes into the atmospheric pressure. This afforded an analogy to the methods of using the high-tension electricity which had been proposed. Instead of having only two series as he had described, they might have a large number of series with reduced pressures, and similar series had been proposed for the supply of electricity, with the advantage of using smaller conductors. This looked easy, but there was great difficulty in the way of supplying electricity in that manner. Supposing that there were one hundred turbines placed between the first high-pressure pipe and the second pipe, which was at half the pressure, there must be another one hundred turbines for the second part of the series, or it would get away to atmospheric pressure and be wasted. So it was with electricity. It was now very certain that the most economical way to use electricity was to use a high potential. Suggestions had been made by Dr. Hopkinson, Mr. Edison, and, later, by himself (Mr. Forbes) as to methods by which the number of lamps might be varied completely at pleasure. It was utterly impossible for the Edison system of parallel distribution to be applied on a large scale, practically and with commercial success. In fact, the larger the scale of that system, the less the profit which could be made from it, as in the case of the telephone after a certain extent had been laid down. But he was equally positive that by using high-tension electricity and diminishing the current with the number of series, they would be able to supply large districts of 100,000 lamps or more from the works at Wandsworth, for example, at a price comparable with that at which gas was supplied in the metropolis. He had paid a great deal of attention to the system of M. Gaulard and Mr. Gibbs, from the time at which they showed it to him in action at the Aquarium in

1882, and he had been struck with the energy with which they had followed out their idea. He confessed that he had never liked to believe in the possibility of such success as they had attained. There was not the slightest question as to the efficiency of the apparatus. The exhaustive reports of the distinguished physicists left no room for doubt upon that matter. It was also a very remarkable fact that such a high efficiency was maintained with the very large variation of the external resistance, which meant a large variation in the number of lamps which were being used. Of course, the rise in the electromotive force when the number of lamps was diminished, which had been referred to by Mr. MacKenzie was an obstacle, but it was no greater obstacle than existed to the use of the direct current a few years ago. He had no doubt, considering the zeal and ability which had been shown by Mr. Gibbs and M. Gaulard in the past, that they would be able to grapple successfully with the present difficulty. Their system very much resembled a series system, because wherever they interposed one of their transformers they went to a lower pressure, so that the transformers really came in to shift the pressure from the high pressure of one main to the lower pressure of the next. Speaking from the theoretical point of view, alternate currents were usually difficult to deal with mathematically, but he thought that persons who did not care much for the mathematical treatment of subjects owed a debt of gratitude to Messrs. Gaulard and Gibbs, for having found out that this arrangement of equality in their two circuits was the most economical system which they could adopt. The mathematics of that arrangement were remarkably simple, and all the difficulties were got over in that way. They had laid great stress upon the fact that the conductor which went the whole length of the circuit was continuous throughout. That, no doubt, greatly diminished the risk of danger from shock. It was quite out of the question to suppose that under proper supervision such a leakage would take place as had been described by Mr. MacKenzie. He was confident that the arrangement of Messrs. Gaulard and Gibbs could be made perfectly safe. Of course in the laying of the wires a good deal of care was necessary to ensure insulation, but there was no difficulty in this if the proper and well-known precautions were insisted upon. As to the defects of the system, he confessed to having a little preference in favour of direct currents, where they could get them, instead of alternate currents. Mr. Gibbs had shown them how the currents could be redressed by a commutator and used as a direct current, and this was essential for electroplating. They could also use the current as a motive power, but there was probably a great loss of efficiency

when the apparatus was used to convert the alternate current into a direct current. He thought that the direct current was generally preferable because of its numerous applications. The arc lamp burnt much better with a direct current than with an alternate current, and the direct current was better as a motive power. To have one of the transformers in each house would be rather an expensive thing, but at the same time they ought to be very grateful that they had two such men to work out a very interesting problem to such a thoroughly practical result.

Mr. Schönheyder wished to know whether the system which was put upon trial at the Metropolitan Railway still existed, and if it had been removed, what was the reason for the removal. Secondly, he wished to know whether the system which had been described got over the difficulty of storing electricity. He believed that it did not, but that the apparatus was only a regulator of electricity. In the absence of a means of storing electricity, there would still be the difficulty, that if anything happened to the machinery all the lights would go out. On the diagram Mr. Gibbs had shown a very high efficiency between the primary and the secondary currents. He should like to know whether there was an equally high efficiency between the indicated horse-power of the engine and the power represented by the primary current. When 90 per cent. of the lights were turned out, was the engine power reduced in that proportion? He thought that it would be very interesting and useful to have another column added to the diagram, showing the proportion of the engine power. The author had stated that it was advisable to put the engine at a place where water power was cheap. It was more important to place it where coal was cheap, for it was possible to construct a condensing engine (of 50 horse-power or upwards) so that the consumption of water did not exceed twenty pounds per indicated horse-power per hour.

Mr. W. B. Esson explained that in advocating the use of incandescent lamps in series he did not mean that ordinary lamps of 100 volts each should be employed. It was possible to get 10-volt lamps of 20-candle power, and he should propose that, if there were two hundred lamps in a building, there should be ten small columns of twenty lamps each, thus giving a difference of potential of 200 volts in each circuit, which was the Board of Trade limit. He believed that it was quite possible to work successfully with the lamps in series, and the apparatus seemed specially suited to this method of lighting, which could be employed without in any way sacrificing its utility as a transformer.

Mr. Bernays said that he had noted that, in describing the engines which were going to be put up in Bond Street, the

author had stated that there were four machines, each with 100 ampères of current and 3000 volts of intensity. He wished to know what reason there was for using a current of such great intensity for working lamps of all descriptions of only about 10 or 20 volts each.

Mr. Gibbs said that the volts represented the electromotive force, and must be sufficient to overcome the sum of the resistances offered by the work done by all the secondary generators on the circuit.

Mr. Talbot said he believed that the Bond Street installation was to be an overhead one. He thought that would be a very dangerous thing in case of a leakage. The wires would be carrying a very high potential, and if a leakage occurred and a person at another part of the circuit accidentally touched one of the generators he would probably receive a shock.

Mr. Gibbs, in reply, referring to Mr. Esson's suggestion to prolong the core of iron wire used in the secondary generators and make a ring of it as in a dynamo, said that he should be glad to know how that could be done practically. The regulation was automatically arranged, so that twenty-four out of twenty-five lamps could be put out, and the remaining lamp would burn in the same way as if all were burning.

Mr. Esson explained that he thought that when some of the lamps were left burning the core had to be moved.

Mr. Gibbs said, that was only one means of regulation. Mr. Nursey had alluded to the cost as compared with gas. He (Mr. Gibbs) and M. Gaulard had gone into that question, and they believed that by their system they could produce the electricity and distribute it over large areas at such a price that they could compete with gas at 3*s.* a thousand. The larger the area the less the cost became. Professor Forbes, who had made a comparison between the action of electricity and the action of water, might remember that at the Aquarium he (Mr. Gibbs) showed him a small diagram, in which the secondary generators were represented as turbines in a closed tube, conveying water, the quantity of water remaining always the same, and the pressure increasing as the number of turbines increased. This corresponded very much to the action of his system, which was that the quantity of the primary current remained fixed, whilst the electromotive force only was increased in proportion as the work increased. He should be very glad to make exact measurements and let Professor Forbes know precisely what was the cost of redressing the current. He believed that the loss was smaller than might be expected. As to the expense of the apparatus, he believed that Professor Forbes would admit that the cost was nothing compared with the economy effected in leads

by the use of the apparatus. The Metropolitan Railway installation was undertaken by permission of the Railway Company, and at the end of the experimental period the Company wrote to say that the working had been very satisfactory. The reason that the system was not carried farther was that there were opposing interests quite outside the question of the efficacy of the system, and, he supposed, inseparable from the transactions of all large companies. As to the storage of electricity, by means of the redresser they could charge accumulators and keep them as reserves. Possibly it would be found that this was really the legitimate work of accumulators. In case of a temporary stoppage they would be very useful. Referring to Mr. Schönheyder's remarks, he (Mr. Gibbs) did not previously know that steam engines could be made to give such an economy with regard to the water employed. As to danger, it could only arise from what he had called culpable negligence; and, with a closed circuit, the danger became infinitely less, even though there might be an earth current or some slight fault. At the time Mr. Nursey received the shock at the Metropolitan Railway the primary circuit must have been very defective. It was placed in a damp tunnel, and there was a considerable earth-leak. If a person was standing on damp ground, there would be necessarily a certain shock. He had frequently stood with his hand upon the terminal through which the primary current was passing continually, without feeling any unpleasant shock. That would have been absolutely impossible if the circuit had not been metallically closed.

The President, in closing the meeting, said that he felt some reluctance in offering his opinion on the subject, because it might be thought that, as a gas engineer, he was biased in one direction. That, however, was not the case. He might mention that one of the consumers of his Company's gas had fitted up his house with a very complete installation of electric lighting: and since this had been done, he had used considerably more gas than had been burnt before. He, thought, therefore, that he might be acquitted of any antagonistic feeling towards the electric lighting. He believed that the apparatus which had been described to the meeting that evening was a step in the right direction. If electricity could be brought into houses, so that it could be used for all purposes, such as arc lights, incandescent lights, motive power, and so forth, its use would become more general than it was at present, provided it could be applied economically. The apparatus which had been exhibited was a very beautiful one, and for his own part he wished it every success. He thanked Mr. Gibbs heartily for bringing it before the Society.

May 4th, 1885.

CHARLES GANDON, PRESIDENT, IN THE CHAIR.

CABLE TRAMWAYS.

By W. N. COLAM.

As is now pretty well known, it was in America that continuous wire cables were first adopted for the purposes of street locomotion. The author, however, in addressing English engineers on the subject of cable tramways, thinks he is best considering the wishes of those present by dwelling but cursorily on the birth, history, and construction of the cable system in America; and in devoting a considerable portion of his paper to a description of the Highgate tramway, which is not only the most recently constructed cable tramway, but the first ever made in Europe. In the case of all inventions which have eventually proved to be of great value, the honours of inventorship have usually been contested. Suffice it to say that the cable system of tramways is of comparatively recent origin, and that the author proposes to leave the question as to who originated it for others to settle. It is doubtful whether the invention in this case would, even at the present time, have been practically worked out had it not been for the fortunate circumstance that a few wealthy men living on the heights of the city of San Francisco had no means of easy access to their dwellings.

The idea of employing a wire cable for hauling vehicles is, of course, very old, and has been utilised in a variety of ways, but the novelty of cable tramways consists in the secretion of the rope beneath the surface of the road in such a manner as not to interfere with the ordinary traffic, and also in the gripping arrangement, which allows cars of the ordinary type to be used. No two lines on the cable system have as yet been constructed alike, but the principle of working has in all cases been the same, and may be concisely described as follows:—

On the cars and under the control of the driver a gripping arrangement is fitted which is extended down through a narrow continuous slot between the rails and into a tube under the surface of the road. Here it is so manipulated by the driver as

to close firmly or partially upon, and, when required, to release itself from, an endless wire cable which is kept constantly moving by a stationary engine placed at any convenient spot along or near the line. The cable is supported on small vertical pulleys at suitable intervals on straight portions of the road, but at curves inclined or horizontal pulleys are substituted according to the nature of the curve. Where very sudden and acute rises occur in the surface of the road (such as at crossings on the San Francisco hills) small inverted pulleys are used to depress the cable and keep it from touching the top of the tube. Such cases, however, are seldom met with in practice.

In the month of August 1873, a few energetic and skilful men succeeded in overcoming the many objections and apparently almost insurmountable obstacles which invariably attend the introduction of new schemes, and the result of these labours was the construction of the pioneer cable line up Clay Street Hill in San Francisco. This hill is very steep, the severest gradient being as much as 1 in 6; and, like most hills around San Francisco, is levelled where intersecting roads cross, giving the longitudinal section of the road a step-like appearance. The street length of this line is 2800 feet, and the altitude risen to in that distance is 307 feet. The first cable used was 3 inches in circumference, and was worked at a speed of 528 feet per minute for 17½ hours per day, and it lasted over two years. Owing to an agreement made with the local authorities, this line had to be constructed in about two months, consequently it was not built quite so substantially as others since. The line soon proved itself a great financial and mechanical success, and in 1877 extensions were made, but not in the same manner. The total length of cable at present in use on this line is 11,000 feet.

The Sutter Street Tramway Co. closely watched the results of the Clay Street trial, and three years and a half after the opening of that line they had converted their line to the cable system, as it had (owing to the grades) hitherto for many years been worked unprofitably by horses. This company has now over three miles of double track, crossing two of the most important thoroughfares in the city. There are four cables employed, all working from one engine-house, three of which work the main line and one a branch line at right angles. The total length of cable in use is 37,736 feet, running at 780 feet per minute. Near the end of the branch line the cars have to pass round a sharp curve, and no difficulty is found in doing so. One year after the completion of this line the passenger traffic had increased 962,370, and the shares of the company previously offered at 5*l.* sold freely at 12*l.* 10*s.* The construction of this line demonstrated the ease with which ordinary lines can be

converted to the cable without seriously interfering with the traffic.

In 1877 the California Street Co. was organised, and opened their line in April 1878. As the route for this line was very steep, at places being as much as 1 in 5·5, it was decided to build it in a more substantial manner than the previous two, which had wood in their formation. The tube here was solely and wholly a combination of iron and concrete, forming a strong homogeneous mass. The cables adopted were also heavier than before, being as much as 4 inches in circumference. The total length of double track is 12,650 feet. The engine-house in this case is situated in a valley and contains two engines, hauling two cables of 8840 and 17,055 feet long, at a speed of 537 feet per minute. Geary, a most central and popular street, was the next route chosen for a cable tramway, which was completed in March 1880. The grades on this line are comparatively easy, the worst being 1 in 10·3. Here the engine-house was placed about half-way along a double track of 13,200 feet. This line has been very successful and free from accidents, notwithstanding it is crossed at right angles by three horse tramways, the traffic of one of which also runs over its metals for a considerable distance.

In 1881 the Presidio and Ferry line of 13,000 feet of double track was constructed. Some of the grades on this line are exceedingly heavy, the worst being 1 in 5·1. There is a curve at the intersection of two streets, the streets from both directions descending towards the curve, around which it was originally arranged for the cars to gravitate; but improved methods have since been introduced, so that either the main cable or an auxiliary one, running at a reduced speed, can be picked up by the cars.

In 1880 the wonderful mechanical and financial success of the San Francisco cable lines excited the attention of tramway companies in other parts of America, and even in the distant English colony of New Zealand. In both places the authorities, having convinced themselves of the value of the system, lost no time in organising lines, and in August 1880 the citizens of Dunedin in New Zealand saw the first cable line (out of San Francisco) opened. Roslyn tramway is practically a single line of 3 feet 6 inches gauge, with turnouts. It is 3500 feet long, and the total rise is 500 feet. The steepest gradient is 1 in 7. An interesting feature of this line is an S curve of 215 feet radius. The success of the Roslyn line induced the Dunedin people to further invest their money in the Mornington tramway, which was opened in March 1882. This line is one mile long, and the altitude attained is 430 feet, the worst gradient being 1 in 6·25.

The next city to recognise the advantages of the cable system was Chicago, and on the results obtained there, under so vastly different circumstances and conditions of climate, depended the spread of the system further east, or the limitation of it to milder climates. It may be taken as fortunate that immediately after the completion of the line, in January 1882, Chicago was visited with heavy falls of snow and severe frost. The cable was at once well tested, and proved to be easily operated, never losing a trip, when all other vehicle traffic was suspended. Again, this winter, the cable system has been uninterrupted, notwithstanding the exceptionally severe weather Chicago has had. The Chicago company had at various times tried all the well-known tramway motors, and they finally reverted to the cable, although the city is practically a dead level, and the company was doing well, as their $100 shares were quoted at $250. The cables on this line are worked from one engine-house, and are so arranged and actuated that three different maximum speeds are imparted to the cable, suitable for the respective districts through which they pass; thus in one place the cable is always moving at 315 feet per minute, at another 716, and at another 804. At the end of the main cable line, instead of switching the cars to the up line, they are run (at half speed) completely around a square block of buildings which entails four considerable right-angle curves. The Chicago company has now a line capable of carrying over 10,000 passengers per hour, and on more than one occasion 100,000 people have ridden on the cars in one day. The annual passenger return before converting was 24 millions, and the first year after 27 millions, with the working expenses considerably reduced.

Market Street, the last line in San Francisco that was converted into the cable system, is by far the most important in that city. For a long time it was thought it would be impracticable to have a cable line in this street, owing to its already very crowded state at certain times of the day. Experience has however shown that out of the eight lines of tramways passing along this street, those worked by the cable are the general favourites, for numerous reasons, amongst others the more uniform speed at which they travel. From 1860 to 1867 this line was worked by steam engines, and by horses from that date to 1883, when the cable was inaugurated. This road has about 10 miles of double track and several branches worked by forty-six heavy and large cars. Five cables of 4 inches circumference travelling at 750 feet per minute are operated from two distinct engine-houses. The total length of these cables is 90,810 feet, and they weigh over 100 tons.

A noticeable feature in this line is a curve of 80 feet radius

which passes in front of the engine depôt, and around which the cars are hauled by an auxiliary cable worked at half the speed of the main line cable.

Lines have been made in Philadelphia, and also one across the Brooklyn Bridge in New York; both, however, have proved failures from an engineering point of view, because in each case the authorities attempted to ignore the patents which cover the construction of good economical cable roads. In Australia the city council of Melbourne has been so satisfied with the report of their engineer, who specially visited and examined the cable lines of America, that they have sanctioned the construction of 27 miles of line in that city, which is now well in hand. The city of Sydney has also granted a company permission to construct a test line of a mile long, with the understanding that considerable extensions will be permitted upon its proving a success.

A cable company has been formed in New York, and the mayor of that city has granted a concession for the construction of a system 72 miles long, part of which is to be street tramways, and part to run above the street as the present elevated railway does. The decision of the council and mayor has not only been influenced by overwhelming evidence of the behaviour of cable tramways, but they have carefully considered the rapid increase of population which is annually being enormously augmented, and they have satisfied themselves that the cable is the only system which will be able to cope with the traffic of a few years hence.

The author has abstained from giving descriptions of the various gripping appliances used on the lines he has alluded to, his object being not to weary the members with described explanations of complicated machinery.*

Fig. 1 shows the wrought-iron tube frames used at Chicago and on some of the San Francisco lines, others have cast-iron tube frames of similar character to those at Highgate.

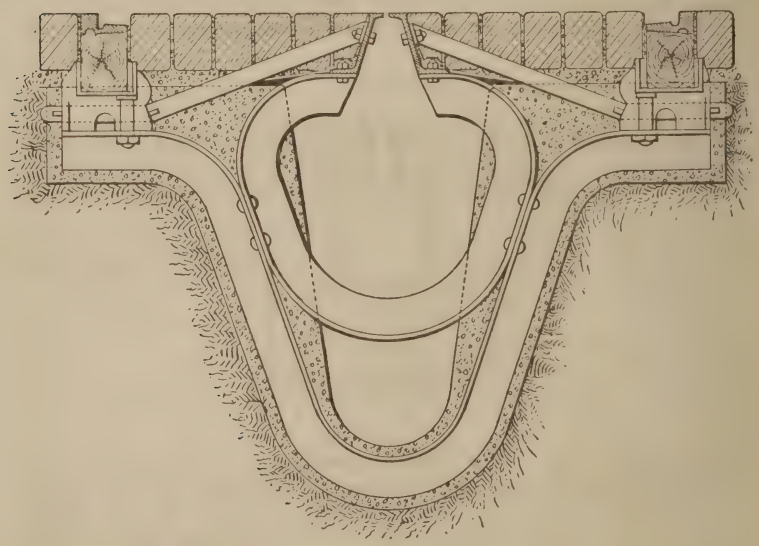
Having given some information as to what has been done in cable tramways abroad, the author will next proceed to describe the Highgate Hill cable tramway.

It is surprising that notwithstanding the rapid growth and great success of the cable system in America and our colonies during the last eleven years, it was not until May 1884 that the first cable tramway in Europe was opened by the Lord Mayor of London, on Highgate Hill. To those who had worked hard in introducing the system into this country, it was reassuring to

* Models were exhibited on the table, showing various arrangements of gripping apparatus.

find how soon after the opening of this line the objections of the local authorities disappeared, and the inhabitants living along the route prepared to vote for further extensions. The power to construct a tramway up the Highgate Hill was obtained by the Steep Grade Tramway and Works Co. during the session of 1882. In the summer of 1883 that company requested the Patent Cable Tramway Corporation (who own all the important patents necessary for constructing such lines) to furnish the designs for and construct their line on the cable system. On the introduction of anything new into this country the idea introduced has usually to pay heavily for the privilege, and

Fig. 1.



this occasion proved no exception, for the surveyors of the parishes through which this line passed were very zealous in watching the interests of their respective districts, and on so small a line as this their several requirements proved serious and most expensive obstacles to the completion of it.

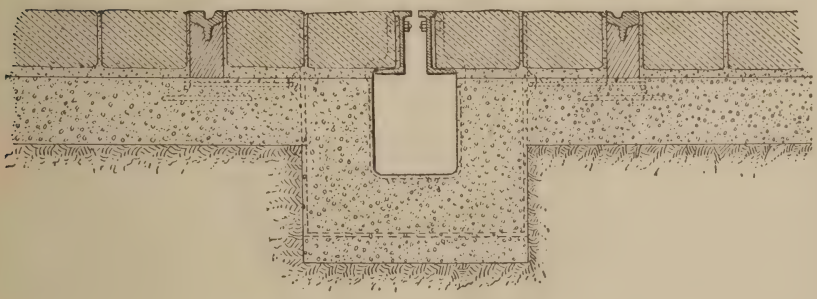
Highgate Hill is a well-known steep incline rising from the junctions of Archway Road, Junction Road, and Holloway Road, in the parish of St. Mary's, Islington; about half-way up the ascent it is intersected by two other parishes, viz. Hornsey and St. Pancras, finishing opposite the old historical "Gate House." The summit of this hill and its surroundings is a great holiday resort for Londoners, and on many occasions this line has been

severely tested by excessive and sudden rushes of traffic, which would have proved too much for any other system of tramway to have met.

The principle of the system working at Highgate is the same as on all the other cable lines in operation, but the details of construction differ in many respects.

The gauge of this line is 3 feet 6 inches, and it commences at the foot of the hill just where the rails of the North Metropolitan Tramway terminate. The total length is 3800 feet, of which 3300 is double track and the rest single. By a reference to Fig. 3, which shows a longitudinal section and plan of the road, a good idea may also be obtained of the direction of the track, and the position of the engine depôt. The total height ascended is 239 feet, and the steepest gradient is 1 in 11. Fig. 2 shows a cross section of the track and tube for

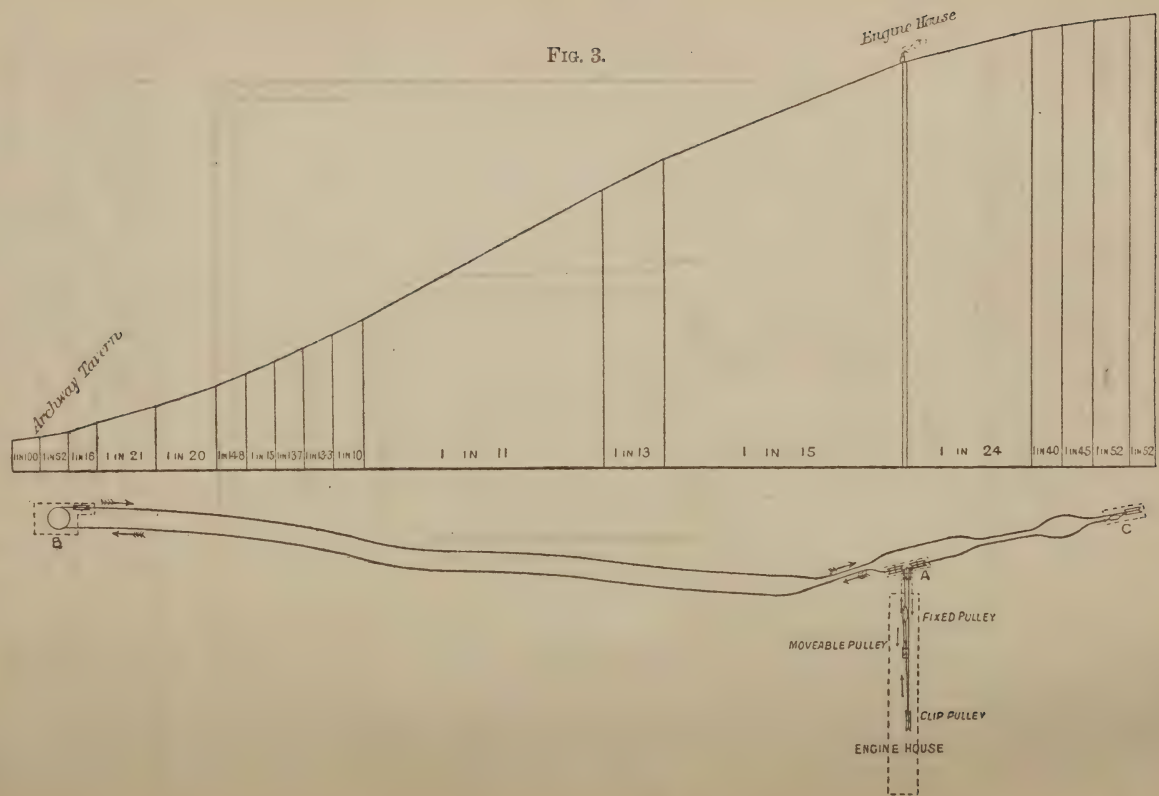
Fig. 2.



receiving the cable. The tube is made of good strong concrete, and is connected with the concrete required by the local authorities for supporting the set stones and rail chairs. Tube frames of cast iron, weighing 120 lb. each, are embedded in the tube, at intervals of 3 feet 6 inches (see Fig. 4). The object of these frames is to support the Z shaped steel rolled beams which form the slot in the road for the gripper shank; these beams, which weigh 36 lb. per yard, are shown bolted to the cast-iron frames. The rail adopted weighs 43 lb. per yard, and is that known as Dugdale's patent. It is supported on cast-iron chairs placed opposite each tube frame, to which they are connected by bolts, firmly securing the gauge true to the slot. The slot is $\frac{5}{8}$ of an inch wide. From the surface of the road to the bottom of the tube is 17 inches, and the width of the tube is $8\frac{1}{2}$ inches.

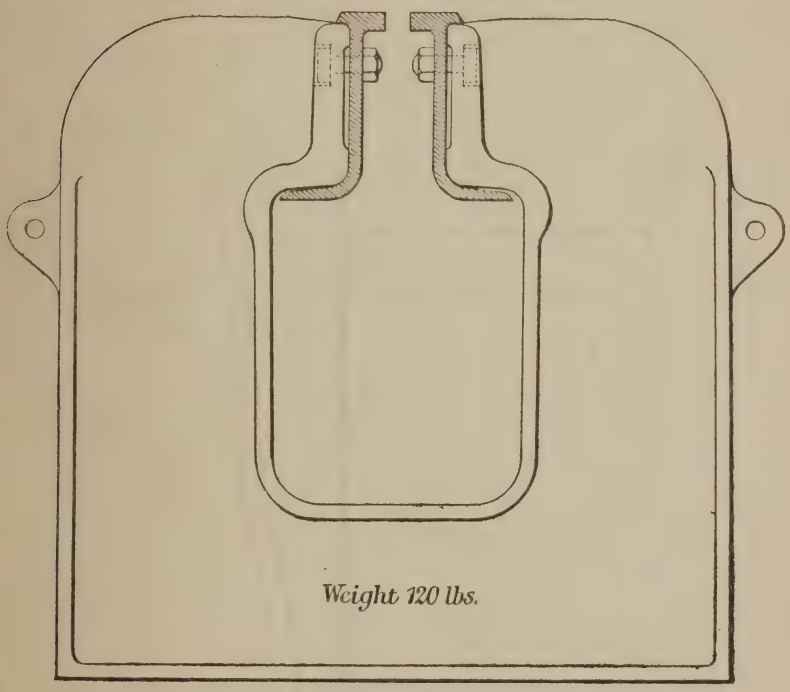
At intervals of 40 feet recesses are made in the concrete for

Fig. 3.


Engine House
Archway Tavern
1 in 100
1 in 52
1 in 16
1 in 21
1 in 20
1 in 14·8
1 in 15
1 in 13·7
1 in 13·3
1 in 10
1 in 11
1 in 13
1 in 15
1 in 24
1 in 40
1 in 45
1 in 52
1 in 52
B
A
C
Fixed Pulley
Moveable Pulley
Clip Pulley
Engine House

receiving the 12-inch cast-iron pulleys which support the cable in the tube (Fig. 6); the pulleys run loose on spindles screwed into castings, which are held in their places by bolts built into the concrete. The pulleys are kept on the spindles by check nuts, which can be easily taken off whilst the cable is in motion, and the pulley removed and replaced through the hatch in the road. The hatch covers are light cast-iron boxes filled with hard wood, and are dropped into cast-iron hatches

Fig. 4.



which rest partially on one wall of the concrete tube, and on the bottom flange of the Z beam. The hatch is built in by the paving, and cannot be detected easily in the road. The pulleys are lubricated by Stauffer's patent lubricators screwed into the end of holes bored up the centres of the spindles. At the single portions of the track, where the cable runs in opposite directions through the same tube, the spindles are made longer, and two pulleys placed on them instead of one. Inclined pulleys with wider flanges are substituted for the vertical

pulleys, where the road curves. All the recesses are drained into the sewers.

There are three portions of single track, and at the junction of the double and single tracks two tubes have to converge into one. The slots in following the tubes also converge, and in doing so leave a portion of the road between the slots unsupported. The designing of these points in cable tramways will always require considerable experience only to be obtained by careful observation during the working of such tramways. The triangle formed by the junction of the two slots is a cast steel trough which is rigidly bolted to the Z beams, and supported by a cast-iron frame from beneath. The apex of the triangle is a strong steel spring screwed to the steel trough. This spring is sprung under the top bend, and against the side of the Z beam, where it is supported on a plate bolted to the side of the beam. Thus the slot is always open for the grip shank of cars approaching the points. The inside of the steel trough is filled with set stones, thus reducing the metal on the surface of the road to a minimum.

The author will next proceed to describe the three brick pits under the roadway, and the machinery in them for diverting the cable at each end of the line, and at the point where it leaves and returns to the tube in passing to and from the driving gear in the engine-room.

1st. The terminal pit at the bottom of the hill, the position of which is shown in Fig. 3. This pit is rectangular in shape, 18 feet long by 10 feet wide, and 7 feet deep from the surface of the road. It is strongly roofed over by rolled iron joists and concrete. It is lighted by gas, and access is obtained to it through a manhole in the road. The machinery inside this pit consists of a narrow cast-iron pulley 8 feet in diameter with V shaped jaw; it is free to revolve horizontally on a pin vertically let into a cast-iron carriage mounted on four wheels. The wheels rest on and traverse the lower inside flanges of two rolled iron joists set at an inclination, between and along which the carriage is free to move backward and forward. A chain is fastened to the lower end of the carriage, and is led over suitable gear to a heavy weight, the object of which is to keep the necessary strain upon the cable.

2nd. The terminal pit at the top of the hill. This is also a brick pit, 18 feet long and 4 feet 10 inches wide and 10 feet deep from the surface of the road. From the plan it will be seen that the parts of the cable approaching and returning to and from this pit are quite close together; the cable has, therefore, to be returned to the tube in a different way to that adopted in the lower pit. As the slot passes over a portion of

this pit, the roofing is arranged to carry the castings for supporting the slot beams. In this pit are two cast-iron pulleys of 8 feet diameter, one placed immediately in front of the other, one revolves in a vertical plane, whilst the other is canted sufficiently to throw its top out of plumb the same distance as from centre to centre of cable when passing through the single track.

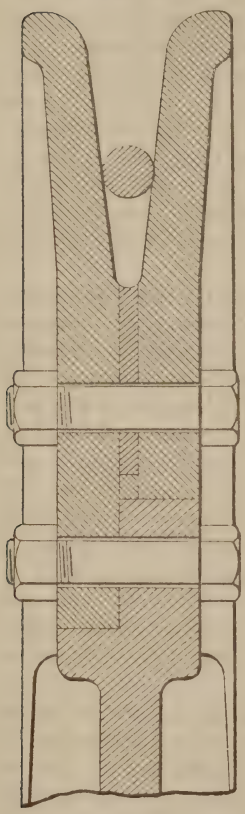
3rd. The pit in front of the engine-house is also of brick, and is so constructed as to be approached from the engine-room. It contains four 8-feet pulleys. The tube slot runs right over the length of this pit. The slot beams here are bolted to special castings, which are mounted on short cross iron joists resting on longitudinal joists. This arrangement leaves the slot open to the pit beneath. The engine-room is in the basement of the depôt, the ground floor of which is used as the car shed.

In selecting the engines for working this line, two important points had to be taken into consideration: first, that they should have a most sensitive automatic cut-off valve gear; and second, that they should be powerful enough to do the work of an extension two miles long. The nature of the work on cable tramways varies so much and so quickly, that within an incredibly short space of time the engines may be seen both working hard and hauled around by the load. The engines chosen were a pair of high-pressure horizontals with cylinders 14 by 28 inches, built by Messrs. Grafton & Co., of Cannon Street. They are fitted with Collmann's patent valve gear, which the author considers a very good one for the purpose, and he is thoroughly satisfied with the way these engines have always done their work, the valve gear being so effective that the brake arranged to act on the fly-wheel is never called into play. The engines can be disconnected and worked separately when required.

On the engine shaft is fixed a cast-iron helical toothed pinion which gears into a larger cast-iron wheel keyed on a counter shaft, which also carries the grip pulley. It is this pulley which does all the work of hauling-in the cable from the road. The jaws are of a long V shape, as shown in Fig. 5, and can be adjusted by thinning down or packing up the wood bolted between the segment castings which form the jaws. Although the author considers this class of pulley gives the cable a rather severe pinch, he is satisfied that it releases the cable freely, which is a great point in its favour, especially when used as at Highgate. These pulleys were made by Grant, Ritchie & Co., of Kilmarnock. Immediately in front of the grip pulley, and in line between it and the four 8-feet pulleys, is the arrangement for taking up the slack of the cable, which is something considerable when new or freshly spliced. Changes in the atmosphere will also affect the length of the cable. This taking-up

arrangement consists of two long rolled joists laid parallel to each other, 18 inches apart and a little above the floor level. On the top flanges of these joists are mounted two 8-feet pulleys, the shaft of the one nearest to the grip pulley turning in journals forming part of a horseshoe-shaped casting, which is arranged to be moved either way along the tops of the joists by suitable screw gearing. The front pulley is fixed on a shaft, which turns in journals bolted firmly to the flanges of the joists. This latter pulley can be moved forward from time to time and bolted down as before, the operation being repeated as often as the stretching of the cable has exceeded the capability of the sliding pulley to take it up.

Fig. 5.



The boilers for supplying the engines are those known as the Babcock and Wilcox sectional type, with water tubes, and are worked up to 100 lb. pressure. This class of boiler is being used very much in the States on cable tramways. For feeding the boilers, a small vertical donkey pump and an exhaust injector have been provided, the latter delivering the water into the boilers at a temperature of about 180° Fahr.

The author having thus far briefly described all the places and machinery through and over which the cable has to work, now proposes to make one round trip with it, and point out its travel. The speed of the cable is 6 miles per hour. Starting from the top of the grip pulley, A, Fig. 3, the cable makes one half turn, and passes to the farthest and fixed pulley on the taking-up gear; it there makes one half turn, and comes to the top, and passes over the pulley in the horseshoe casting, where it is again sent down and straight off to the bottom of the left-hand pulley, which directs it up to the large pulley set in line with the tube in the road, whence it is sent on its way down the hill supported on the pulleys. On nearing the bottom of the hill the tube is not led straight into the lower pit, but is carried round between the tracks of the first turnout. The cable leaves the tube at this point, and passes through 10-inch pipes into the lower pit, and on to the horizontal pulley B,

which directs it into the up-hill tube, in passing through which it is supported in the same manner as in the down-hill tube. Upon reaching the upper terminal pit, C, the cable passes clear of the first pulley on to the top and over the second, around which it makes a three-quarter turn, and is sent up to the top of the first pulley, which is slightly canted to return it into the tube close to the uphill portion of the cable; from it the cable passes down the hill until it reaches the pulleys which deflect it downwards and into the engine-room, where it rises gently until it again reaches the grip pulley from which it started. The long length of cable which passes, in sight, through the engine-room, enables any fracture of a wire to be quickly detected, which can be remedied at once or at night as the importance of it demands. The cable used is 8200 feet long, and is 3 inches in circumference. It is made up of 114 crucible steel wires of No. 16 wire gauge, formed into six strands wrapped around a hempen core. The guaranteed tensile strain of this cable was 80 tons to the sectional square inch.

Fig. 6 shows the lower portion of a car on the line with the gripper fixed in its place and the gear for actuating it attached. The gripper is shown with the cable in its jaws and about to pass over a pulley. It is made of cast steel, and consists of two principal parts, one of which is in the same piece with the lower and movable jaw, and the other with the upper and fixed jaw. The wedge shown, in being forced into or withdrawn from a shoe raises or lowers the casting holding the lower jaw. The cable is thus seized firmly, or slightly, or allowed to run through the jaws, as it may be required that the cars should travel full speed, slow, or stand still; and by opening the jaws wide the cable automatically leaves the gripper. The jaws are lined with soft pieces of cast iron, which can be easily and quickly removed and replaced. Two grippers are fitted to each car, one on each end.

The grippers have hold of the cable whilst descending as well as in ascending the hill, and only release it at the termini and in passing the pulleys in front of the engine-room. At the latter place, as the cars slowly near the pulley, the drivers open their grippers wide, and the cable automatically leaves the jaws. The cars then descend by gravitation along the few feet of deviated track, the object of which is to take the grippers past and clear of the pulleys. On the cars again reaching the straight track, the cable automatically slides into the jaws of the grippers left open to receive it, and the drivers have only to screw up their grippers, when the cars are again carried on at the speed of the cable.

This being the first cable line in England, it was for obvious

reasons, considered advisable to try more than one form of car, and at Highgate there are now four distinct types of cars working.

1. An ordinary short-wheel-base tramcar, with inside and outside seats, but not arranged to carry a gripper.

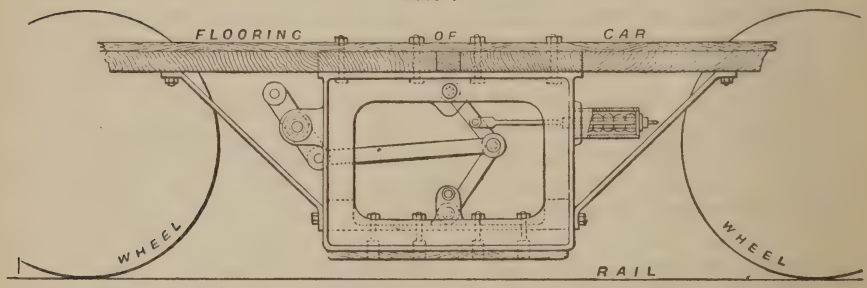
2. A dummy or open car which has a gripper at each end. This car and the first are worked coupled together, demonstrating the ease with which the rolling stock of other lines of any system can be attached to and carried on by the cable cars.

3. A bogie car of an ordinary design with gripping arrangements at each end.

4. A long bogie car to carry 60 passengers, fitted with gripping arrangement each end; this has proved a very remunerative type of car.

All the cars are fitted with two classes of brakes, one of common design which acts on the tires of the wheels, the other a slipper brake (Fig. 7) which acts vertically on the rails.

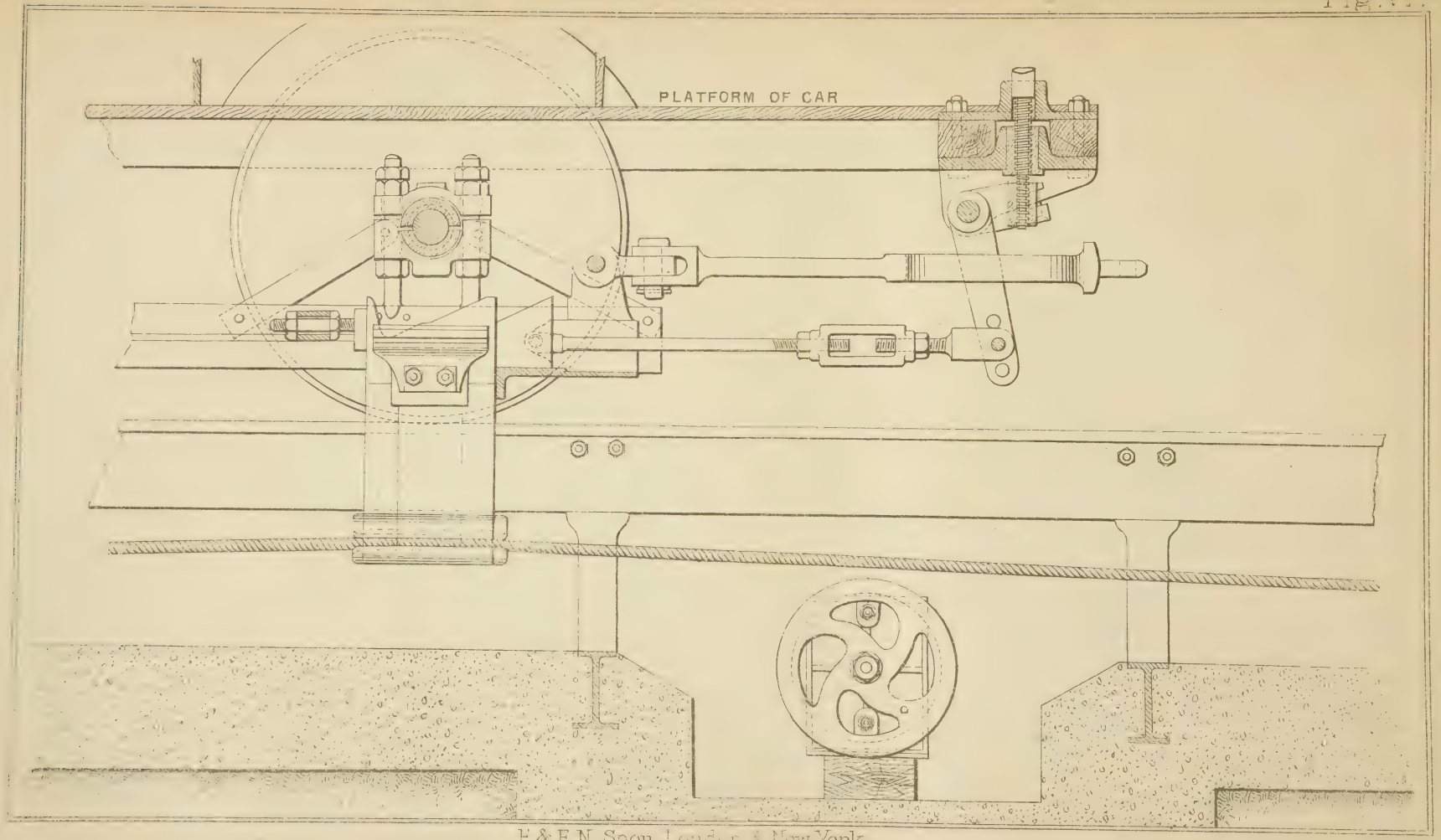
Fig. 7.



The latter brake consists of an iron frame firmly secured to the bottom of the car; inside this frame slides a shoe fitted with a long block of hard wood, which the driver through an arrangement of powerful levers, can quickly force down on the rails, thus utilising a part or the whole of the dead weight of the cars and passengers. This brake was severely tested by Major-General Hutchinson of the Board of Trade, who tried it on a car which was allowed to gravitate until it acquired a velocity of about 20 miles per hour on a grade of 1 in 11, when the car was brought to a standstill within 30 feet.

The Highgate tramway has now been working most successfully for the past eleven months, during which time it has carried 563,408 passengers, with but two mishaps, which the author is glad to be able to say had nothing whatever to do with the system. Time will not allow now of a full explanation of these

Fig. VI.



E. & F. N. Spon, London & New York.

unfortunate occurrences, but the author suggests that all interested in the matter should refer to the Board of Trade inspector's report, and be guided by it alone.

Engineers will doubtless see at once that the cable system admits of a large increase of traffic, with but small proportionate increase in working expenses. They may, however, be astonished to hear that the Highgate line has carried 100 per cent. more passengers, with an addition to the consumption of coal which was practically nil. It must be interesting to know that every cable tramway constructed and worked up to the present time has paid a dividend after the first year's working. The author cannot now give details of the comparative constructive and working costs of cable tramways, but he gives it from his experience that a saving of about 50 per cent. can generally be obtained in a cable tramway of three miles, the cable travelling at 6 miles per hour, with a five minutes' service of cars, allowing also interest at 6 per cent. on cost of construction and equipment, as against a horse tramway with an average speed of $4\frac{1}{2}$ miles per hour.

There is little doubt that the time has arrived in England when horse traction on tramways must be superseded by mechanical motors. Therefore, in comparing the relative merits of the known systems able at present to compete, it will be important to remember that there is a large mileage of tramway rails already laid in various parts of the United Kingdom which would be too light to bear the heavier traffic of locomotives depending on adhesion; thus at the outstart giving the cable system, even on level roads, an advantage over steam, compressed air, and electricity, an advantage which increases very rapidly with the severity of the grades, until a point is reached when the cable system only can ascend, and even then work almost as easily as on the level. The latter statement is perhaps at first hard to believe, but its correctness will be apparent when it is remembered that the cable cars in descending hills still retain a hold of the cable, thus utilising their weight due to gravity in hauling up the ascending cars, a power which on all other systems is thrown away by the application of brakes in descending grades.

The author will conclude by tabulating some of the advantages of cable tramways, as follows:—

1. The steepest grades are as easy to work as levels, the weight of descending cars being utilised to pull up ascending cars.

2. The cars when taking up or setting down passengers are absolutely stationary, the hauling power being practically detached for the time; thus in cases of necessity to avoid

collision or danger to life the cars can be brought up instantly.

3. The method of working is noiseless. The stopping and starting of cars is performed so gradually as to be almost imperceptible.

4. Fewer cars are required on the road to do the same work, because the more uniform speed gives a greater mileage per car, and consequently a larger carrying capacity.

5. Sudden increase of traffic can be accommodated to a practically unlimited extent by merely bringing more cars on to the line, the motive power being already provided, and in action.

6. Considerable reduction in wear and tear of the surface of the road as compared with horse haulage, and of the rails as compared with lines on which engines are working; the latter often requiring about 100 per cent. more dead weight to secure adhesion.

7. The traffic is not affected by snow or frost, as evidenced by the following extract from a letter by the superintendent of the Chicago City Tramway Company:—"Though we had at one time frost (snow) two and a half feet deep, we did not discover any bad effects on our construction or operation."

8. It is the only mechanical motor which does not introduce more weight into the cars than is required for horse tramways, thus saving a renewal of rails when laid lightly for horse traction.

9. It is the only system which prevents cars running away in descending a hill, when all brakes have failed.

10. Its very low cost of working, as compared with other systems, ensures its financial success.

11. It is the only system which is not seriously affected by the proverbial dirty tram rail.

12. Perfect cleanliness of carriage way—a very important sanitary advantage.

13. The extinction, wherever cable traction is introduced, of the barbarous horse system—a cruelty unworthy of humanity and civilisation.

DISCUSSION.

The President, in inviting a discussion, remarked that the subject might almost be said to be a new one to the engineers of this country. Those who gave increased facilities for locomotion were deserving of the thanks, not only of the Society of Engineers, but of the world at large. The author had given thirteen reasons why the cable system was to be preferred to all

others; and certainly the arguments which he had brought forward went far to support the reasons which he had given.

M. MANIER asked what arrangement was made for enabling two cable tramways to cross each other at right angles.

Mr. A. T. WALMISLEY said that the construction of cable tramways, where other systems were unsuitable, was one of the questions with which the engineer of the present day had to deal; but although the cost of working was less than that of other systems, the first cost was so much greater that an engineer would hesitate in many cases before recommending the cable system. For steep inclines, however, such as Highgate Hill, the system was very suitable. But in spite of the author's powerful arguments he was not prepared to endorse the opinion that for very crowded thoroughfares, or upon a level road, the cable system would be economically applicable. An Act of Parliament was obtained last year for applying the cable system in a tunnel to be constructed under the crowded thoroughfare of the Borough and under the Thames, for conveying passengers to and from the City. They would all look forward with very great interest to the execution of that scheme.

He was sure that they were indebted to the author for bringing before them such an interesting account of the Highgate Cable Tramway to which he was engineer. They must all agree that the Highgate system was very complete in its design, and that no point of importance had been overlooked in the consideration of the details.

Mr. CLAUD SCOTT thought that Mr. Colam had made a slight error in stating that 100 per cent. more passengers could be carried with the same consumption of coal. He (Mr. Scott) had had much to do with the Highgate line, and a very strict record had been kept of the coal consumption from the beginning. In the winter, when passengers were scarce, they carried somewhat under a thousand a day, and the coal consumed was about 35 cwt. On Easter Monday about 7000 passengers were carried, and exactly the same amount of coal was burnt. He put this down to the fact that rather more people were carried down the hill than were carried up. The assistance which was afforded by their weight helped to carry the passengers up the hill without an additional consumption of coal. During a heavy fall of snow which occurred one Sunday about six weeks previously, the cars travelled up and down the hill without the slightest trouble, whilst the horse-cars and busses running to the foot of the hill were not at work for 2½ hours, while the road was being cleared of snow.

Mr. C. A. KNIGHT said that where the system had been established it had been most successful. The chief doubt which was

urged against it was that snow would interfere with the working, but experience in Chicago had proved that objection to be quite groundless. The snowfall at that place was very considerable, but it had never caused any difficulty in the working of the line. The economy of the cable system had been thoroughly established by the fact that the cable roads were paying a good dividend. The failure of the line at Philadelphia, which ran for a short time, was due to improper construction. He was well acquainted with the system in operation in Chicago, where there was one cable of about 21,000 feet in length. He fully believed that the cable tramway system would be a success in England, as it had been elsewhere, and would be generally adopted. Mr. Colam, in enumerating the advantages of the system, had omitted an important one—the absence of the smoke and gases which emanated from the ordinary mechanical means of locomotion. This characteristic was particularly valuable in connection with the application of cable tramways on underground lines, as no special or artificial means of ventilation would be required where that system was used. In reply to an inquiry made by the President, the speaker added that he believed that the longest cable in use was 24,000 feet, the length of the line itself would be about half of that.

Mr. W. S. Lockhart said that he had taken some interest in the Highgate tramway, for it passed his door. He should like to know from the author of the very interesting paper how the ropes were spliced. He noticed that the paper stated that the ropes passed automatically out of the grippers, and automatically into them again; but at Highgate he had observed that at the end of the line, after a station was passed, the conductors went forward with hooks, and a sort of fishing for the rope went on. He wished to know whether that was a normal circumstance, or was merely due to some slight but remediable error in construction. The author spoke of the sheave at the bottom of the hill as a sheave. He supposed that as a matter of fact it was simply a U-shaped sheave, having no gripping action on the rope. He did not notice much in the paper about the cost. Perhaps the author would give a few details on that subject. He (Mr. Lockhart) believed that in the construction of the Highgate tramway there were some abnormal circumstances increasing the cost, and that the grade of the road had to be considerably altered in parts. The author, indeed, had alluded to the requirements of the district surveyors. But putting aside such special expenses, what would the line cost under ordinary circumstances?

As a mechanical system, the Highgate tramway was a

marked success, but he could not altogether endorse what the author said with regard to the wish of the inhabitants for its extension. The route of the Highgate line, also, was much more noisy than it was formerly, because the roads had to be pitched in consequence of the construction of the line, whereas formerly they were macadamised. The cars themselves in passing and repassing were very noisy. If that objection could be obviated it would be a marked improvement. He considered that the system would be still more convenient for underground haulage than for ordinary tramwork. He could not but think that in many parts of London the system would be very dangerous, and that it was more suitable for thinly populated neighbourhoods than for streets where there was much traffic. He understood that it had been proposed to extend the line from Highgate to Finchley, but he could not understand how a dividend could be earned upon such an extension, as there would be very few people to travel. He believed that the bill for the Finchley extension was lost.

Mr. W. Booth Scott, alluding to the noise which had been spoken of by the last speaker, said that at the points on the Highgate tramway where the line changed from single to double and *vice versâ*, there certainly was a considerable noise occasioned by the passage of the gripping apparatus. The Highgate line combined, in its very short length, all the difficulties which would be met with in lines of any length. It commenced at the bottom of a steep hill with a double line, and before the top of the hill was reached the road narrowed, and the line had to become single. Again it changed to double, and then once more to single. Horizontally the line was far from straight, and vertically there were several changes of gradient. He had seen the cable tramway in operation in Chicago, and he knew no reason why it should not be applied to many of the streets of the metropolis.

Mr. Schönheyder said that it was interesting to see in the diagrams exhibited by the author the various ideas which engineers had had in dealing with the problem of cable tramways. He criticised some of the San Francisco tube-frames as being loose and flexible in construction, and considered that the slot would be liable to be closed up in consequence of the pressure on the sides. The Chicago system seemed to be, on the other hand, a stiff and substantial arrangement, although, perhaps, rather expensive. He wondered that such a section of rail as was shown in that system was tolerated in a street with much traffic. It was likely to wrench off the wheels of a lightly constructed carriage. In the section adopted for the Highgate tramway it was quite impossible for the slot to

become closed by any amount of pressure. He did not see how the wrought-iron rails at the slot were fastened. In describing the pulleys for guiding the rope, the author said that they were mounted on pins, these pins being stationary. He did not know whether the work upon them was heavy, but they were intended to last a long time, and he considered that in such a construction the working would in time become very unsatisfactory, the pins, of course, wearing smaller and the pulleys larger. As to the grip pulley shown by the author, he (Mr. Schönheyder) should have fought shy of such an apparatus. It might bend the rope sharply by holding it too tightly, and then it would be very difficult to get the rope straight again. The pulley appeared to be too small for its work. It would be better to have larger pulleys with some kind of grip arrangement, like the well-known Fowler grip pulley, where the jaws opened of themselves directly the pressure was taken off. In describing the engines the author had said, no doubt rightly, that it was necessary to have a very good automatic expansion gear, and he had not the least doubt that the gear adopted fulfilled its purpose very well, and he admired the ingenuity of the designer, but he should be very sorry to adopt such a thing. It would, he thought, be impossible to construct a greater conglomeration of excentrics and levers and rods to effect automatic expansion. The same thing could be done at about one-tenth of the cost, and it would work satisfactorily. He should have thought, also, that it would be much more economical to adopt condensing engines. It was well known that condensing engines could be worked with as little water as the high-pressure non-condensing engines, or, in fact, with less. He believed that the slipper brake was tried some years ago on railways, and was condemned on account of its being dangerous. Of course it might answer at lower speeds, though not at high ones. It was a very old invention.

Mr. R. W. P. Birch said that it would be interesting if the author would tell the meeting how fast he had known the cars to travel on the cable principle. As he understood, the speeds mentioned by him had not been more than four to six miles an hour. It had, however, been said that the system would be suitable for working the underground railways; but on those lines the trains travelled from twenty to thirty miles an hour between stations. He (Mr. Birch) would like to know upon what experience the opinion that the cable method would answer for this work was based.

Mr. Kincaid congratulated the author and the Society upon the very interesting paper they had heard. He said that even

if the system of cable traction was the most admirable that could be adopted, there were legal difficulties in the way of adopting any system of mechanical traction in this country without a sanction which it was very difficult to obtain. Cable traction was most valuable where the traffic was very large, and that was just the condition under which the Legislature was very jealous of allowing mechanical traction to be used at all. The existing prejudices were chiefly due to the imperfections and annoyances which had shown themselves in the various forms of locomotive hitherto used. Cable traction was free from those objections. In this system of traction it was very necessary to have powerful brakes. Slipper brakes had been used on the Highgate tramway, and the Board of Trade, seeing that they were successful there, had brought them before several other tramway companies. His own opinion was rather in favour of the ordinary system of applying brakes to the wheels. The slipper brake, as applied at Highgate, was fixed under the centre of the carriage, and, in his own opinion, was neither so safe nor so reliable as the ordinary brakes which were applied to the periphery of the wheels.

It was curious to note how many different systems of laying the lines had been adopted in connection with cable tramways. Although the cable system could be used under any circumstances, yet great variations of details had to be made in almost every case. Although, as Mr. Scott had said, almost every form of difficulty appeared at Highgate, yet a great deal of ingenuity would still have to be shown in applying the cable system to other roads, in consequence of the existence of sewers and pipes and mains of various kinds. He hoped that the last reason which Mr. Colam stated in favour of cable tramways would be one which would induce the authorities to allow the system to be extended, and that was the great cruelty inflicted upon horses by employing them to draw tramcars up gradients for which they were quite unsuitable.

Mr. P. W. Morison said that he had been practically connected with the cable system of tramroads. There was no insurmountable engineering difficulty in designing them, although, as the last speaker had stated, some ingenuity was called for in particular cases. The cable system had a very great advantage over other mechanical traction systems in being able to work in such foul rails as tramways generally had. The foulness of the rails produced a friction exceeding, he believed, 15 lb. per ton of load. Locomotive engines on tramways also laboured under the disadvantage of having their comparatively delicate machinery exposed to dust and dirt,

which made it necessary to keep spare engines in the yard to provide for repairs. Another advantage possessed by cable tramways was that the cars could be taken up steep inclines without any necessity for extra weight to secure adhesion, as in the case of a locomotive engine, and therefore light rails could be employed on cable lines. He believed that in the locomotive tramway in Sydney the weight of the rails had reached 92 lb. per yard, found necessary to carry the locomotives required for the work under their unfavourable conditions.

Mr. Arthur Rigg said that he spent about two hours last autumn in examining the tramways in Chicago. He observed that the grippers used there were about a yard long and were covered with wood, and the cables were extremely well greased. He should have thought that iron grippers, as described by the author, would be more likely to wear the cable than the wooden grippers used at Chicago. The machinery there seemed to work very successfully, and the cars were easily stopped when running at an unusually fast speed for road tramways, a speed which seemed to be more than six miles an hour, or at all events it was much faster than he had ever ridden in any London tramcar. There were double pairs of horizontal engines for driving the cables, and the necessary grip was obtained by leading the cables a succession of times round two driving pulleys, and then, far away behind, there was a loaded pulley which kept up the needful strain. He should regard that as better than a single pulley where there would be a great tension upon the cable. All strains would be greater at Highgate than at Chicago, because, at the latter place, the line was absolutely a dead level. The cable used at Highgate was 1 inch in diameter. It looked a little light compared with the one which he saw at Chicago.

Mr. C. E. Audain said that he was sorry the author had not given information with regard to that great point which engineers had always to consider before they adopted any scheme, namely, £ *s. d.* Mr. Walmisley had remarked that the prime cost in the cable system was greatly in excess of ordinary systems. There could be no doubt that, in a case like that of the Highgate incline, the cable system was the best one which could be used, but in London there were very few gradients like those at Highgate; and if there was any considerable difference of first cost between the cable and the horse systems, he thought the horse system would have the preference in ordinary cases. With regard to the effect of snow, he had himself seen the Highgate tramway working satisfactorily on the occasion referred to by a former speaker.

But they did not have snow often enough in London to necessitate a special system of traction to meet its difficulties.

The PRESIDENT, referring to the effect produced by cable tramcars on horses drawing other vehicles, said that his experience was that unless a horse was well trained he did not like to see a vehicle moving along without any visible means of propulsion. He believed this would be a practical difficulty in crowded thoroughfares.

Mr. BOOTH SCOTT, alluding to the same point, said that at first the horses were startled by the tramcars at Highgate and pricked up their ears, but now not one horse in fifty took the slightest notice of them. He resided near Highgate, and had frequently observed them; it would almost seem that they had means of communicating with one another.

Mr. COLAM, in reply, dealing first with the question put by M. Manier as to how cable tramways could cross one another at right angles, said that the crossing might be effected in a variety of ways. The Geary Street line, to which he had alluded, crossed one of the other lines. [The speaker then sketched on the blackboard the arrangement adopted in this case.] The method here employed had been working with great success for the last six years. He owned that, as Mr. Scott had said, he had not stated quite exactly the figures in reference to coal consumption, for he was afraid the actual figures would hardly have been credited. On the 6th of last month there were 7048 passengers carried on the Highgate tramway, and on the 2nd of April there were 4090, and yet the consumption of coal was about 36 cwt. in each case, and what little difference there was in the rate of consumption was due, he believed, to the fact that different men were firing on these two occasions. A question had been asked as to the length of the longest cable line. The longest line was 44,200 feet, of a double track, and the cables used in working it were 90,610 feet long. As to the splicing of the cables, the question was a rather difficult one to answer, because the process of splicing was a very complicated one; but he could say that the part spliced was, if anything, stronger than the other portion of the rope. A splice extended over a length of about 40 feet.

It had been suggested that on the Highgate line, when the cars reached the termini, the conductors had to fish with hooks for the cable, but that was not the case; indeed it would be dangerous to attempt to lift the cable direct in such a manner, for either the hook would be suddenly jerked out of the man's hand, or he would be himself pulled to the ground. On some cars, however, it is necessary for the conductor, when starting the car on a particular spot, to pull up with a hook the strap of

a pulley, hinged at the other end, by which the cable was raised into the open jaw of the gripper.

The place referred to in the paper, as that at which the cable automatically leaves and returns to the gripper, is the spot where the cars gravitate in front of the engine-house. As to the section of the pulley at the bottom of the hill, it was really the V shape.

Two gentlemen had inquired as to the cost of constructing cable lines. In the case of the Highgate line, the promoters had to make two sewers, going from the top to the bottom of the hill through two different parishes. Apart from all the superfluous work of this sort, the cost of the Highgate line, equipped with machinery and everything ready for working, was 18,000*l.* for a mile and a half of single track. Under other circumstances tramways could be constructed more cheaply than that, namely, at the rate of 10,000*l.* a mile. With regard to the noise which had been alluded to, he believed that what little there was attracted notice only because there were no horses' feet to drown the sounds of the cars. If they could hear the ordinary horse-cars running along the line and crossing from one line to another without the sound of the horses' feet, quite as much noise would be observed as in the case of the cable line.

Mr. Schönheyder had alluded to the construction of the Chicago road. He (Mr. Colam) considered that that construction was intended to get rid of a great deal of money, and the line was certainly neither the most economical nor the strongest which could be made. A very heavy traffic upon a line of that construction would most decidedly tend to close the slot. The rail shown was a very common section in America, but he did not like it. The construction of the pulleys, upon which Mr. Schönheyder had commented, was found practically to work well at Highgate. As to the arrangement of grip-pulley jaws, he knew (as he had stated in the paper) that its action was rather severe on the cable, but others had been tried with nothing like such good results as were obtained at Highgate. It was well known that a grip pulley which would release a cable very well under some circumstances, would occasionally fail to do so when working cable tramways, because the outgoing strains were not uniform. In many cases where cables have not been freely released, permanent kinks have been the result, thus seriously lessening the life of the cable. As a practical illustration of the effect these pulleys had on the cable, he was glad to say he had with him a specimen of cable which had hauled 300,000 tons of coal 35,000 miles and which was still in fair condition. He agreed with Mr. Schönheyder that

the model of the valve gear looked very complicated, and as an English engineer he was very much opposed to complicated valve gear; but he had found at Highgate that there was very little wear indeed upon the different parts, and the cut-off had been most efficient. As to the mending of the cable, it could be very readily and quickly done; but he was glad to say it had not often been required hitherto on the Highgate line.

Mr. Birch had asked what was the greatest speed at which the cable travelled. The greatest speed of which he (Mr. Colam) had ever heard was 12 miles an hour; but they were going every day in Chicago at 10½ miles an hour. In that city the speed was suited to the street through which the car was passing, being reduced where the traffic was more dense. The driver could go as slowly as he liked.

As to the slipper brake which Mr. Kincaid had criticised, he (Mr. Colam) was certainly very proud of it, for it had proved quite successful at Highgate, where the line could not be safely worked, trusting to a wheel-brake alone. Experience had shown that it was, as Mr. Kincaid said, wrong to place the slipper brake in the centre of the car. At Bradford he had seen it applied to one of Kitson's locomotive engines, and it was placed between the bogie wheels where it was undoubtedly more effectual. Mr. Rigg had remarked that the grippers used at Chicago were different from those described in the paper. In the latter the motion was sent through a series of screw levers and wedge, and was very gently applied. The Chicago grippers were worked by a long lever which, in the hands of a new driver, gave a little trouble because the power was applied too rapidly, and the cars were jerked ahead. This could not happen where there was a screw and wedge. He found that there was nothing better than soft cast iron for the lining of the jaws of the gripper. Wood had been abandoned in Chicago because when wetted by the rain it was rapidly cut away.

As to the effect of the cable cars upon the horses running on the roads, his experience was much the same as that of Mr. Scott. The horses all round the district had become familiar with the cars, and they were now tolerably good friends. He could not say the same with regard to the tramways worked by steam at Leeds and Bradford. So long as the engines behaved themselves, the horses treated them pretty much as they treated the cable cars at Highgate; but every now and then the engine gave a sniff or a snort, to which noises and the steam the horses decidedly objected. He thought that the cable tramways certainly had again the advantage in this respect. With regard to the cost of the construction and equipping of cable tramways generally, it was found that with a minimum length of three

miles the outlay was about the same for cables as for horses; but in the case of cable lines of greater length, the comparison of cost was even more favourable.

The PRESIDENT, in closing the discussion, said that the cable tramways recalled the days of his youth when the Blackwall Railway, which was about the first railway in London, was worked by means of ropes. That system was very well so long as the ropes held, but occasionally there was a breakage, and consequent delay while the ropes were being mended. He did not suppose that anything of that sort was to be feared in the cable tramways. He had some little doubt as to the general applicability of the cable system, but it appeared suitable for steep gradients and short distances. They were very much indebted to the author for bringing the subject before the meeting.

June 1st, 1885.

CHARLES GANDON, PRESIDENT, IN THE CHAIR.

PORTLAND CEMENT.

By HENRY FAIJA, M. INST. C.E.

ALTHOUGH a great deal has from time to time been written about Portland cement, the author is bold enough to think, and also to say, that very little is known about it except to those intimately connected with its manufacture or who happen to be large users, and have, therefore, been obliged to make themselves thoroughly acquainted with the subject. In general, little is known about it—so little, indeed, that the specifications submitted to manufacturers are often absolutely impossible to work to; and even supposing they could be, the result would probably be a material of which at present nothing is known; it might in some instances do the duty of cement, but even that is doubtful, and it certainly would not be a Portland cement.

The error into which most of the draughters of these specifications fall is that they have heard or read that a cement should be extremely finely ground, the finer the better, also that it should be heavy; therefore by inference the heaviest weight is specified in conjunction with the finest grinding, and these unfortunately are properties which cannot both be obtained in the same cement. It is not at all uncommon to see in a specification that the cement shall weigh 120 lb. to the striked bushel, and be so finely ground as to leave only 10 per cent. of residue when sifted through a sieve having 4900 holes (70 by 70) to the square inch. Now it would be impossible to produce a cement which would comply with these requirements. It should be remembered that the finer a cement is ground the more bulky it becomes, and consequently the less weight per striked bushel. The weight given above, 120 lb. per striked bushel, would probably correspond with a fineness or rather a coarseness of a residue of perhaps 30 to 35 per cent. on the 70 by 70 sieve, and 20 per cent. on the 50 by 50 sieve; whilst the fineness mentioned, 10 per cent. on a 70 by 70 sieve, would

correspond to a weight of perhaps 106 lb. to 110 lb. per striked bushel. Of course the bushel measure is to be filled by one or other of the recognised methods, so that it shall be filled as lightly as possible, and in no way touched or shaken until the cement in it has been struck level on the top. For the practical purposes of the user, however, the weight of the cement is now acknowledged to be of very little service in assisting the determination of its value. It is a test which originated with the manufacturers, and to the manufacturer working always with the same raw materials it is of use, for it enables him to form an opinion as to the degree of calcination to which the cement has been subjected, the harder burnt producing the heavier clinker. But to the user the weight is no guide whatever, since peculiarities in the raw materials, without being in any way detrimental, may produce on calcination a heavier or a lighter cement. In the author's testing-room a weight test is carried out if it is specially asked for; but as for being any guide or assistance in forming an opinion of the value of a cement it is absolutely useless, and, except when asked for, he has not carried out a test for weight for many years.

Another matter in which specifications often err, is in the wording not being sufficiently explicit. The following is a very favourite sentence, which from its popularity must be derived from some published work or specification of which the author is not cognisant; it is very misleading, and has, within his knowledge, led to more than one dispute. It is, "The breaking weight per square inch seven days after being made in a mould and immersed in water during the interval of seven days shall be," &c., &c. Now, the wording evidently reads that directly the cement is gauged and filled into the briquette moulds, moulds and all are to be put in water, because it would be evidently impossible to remove the briquettes from the moulds until they were set, a proceeding directly contrary to practice and to reason, but one which the author has seen insisted upon. Again, if the briquettes are not placed in water until twenty-four hours after they are gauged, which is the usual practice, it would become an eight days' test, i. e. briquettes gauged on a Monday would be tested on the Tuesday week, leaving seven clear days in between, which, of course, is in favour of the manufacturer, because his cement has one day more to acquire its strength; but the wording is altogether vague and indifferent, and, worst of all, read it any way, it is not in accordance with ordinary practice, and comparative results between different samples of cement cannot be obtained if the same means and procedure are not adopted in every instance.

Specifications are matters which affect the manufacturer more

than the user; the user has a right to ask for what he likes, and if the manufacturer undertakes to supply him, he is bound by his contract to do so. It is, therefore, surprising that manufacturers have not before now drafted a specification, and formulated a manner of procedure for carrying out a cement test which would satisfy the requirements of a good cement, and which they would be prepared to work up to. To enumerate a tithe of the absurdities which appear in cement specifications would take up more time than can be spared, and their consideration would not be profitable. Having given two instances, it may be at once stated that a cement specification is about the easiest and shortest to write, when once the nature of the material is known, and the particular requirements of the case ascertained. The object of testing cement is to determine its value as a constructive material; the object of the specification is to define the value which is required, and unless this is clear and explicit it is hardly possible for the manufacturer to comply with it, or for the test to be of much value.

So far as experience goes, the ultimate strength of Portland cement is not known, nor for practical purposes is it necessary that it should be. A good Portland cement is known to continually increase in strength for several years, and there is no reason to suppose that it will—within the limits, at all events, of the life of other constructive materials—in any way deteriorate. It must, further, be borne it mind that cement is always too strong for the purpose for which it is to be used, and that it is always weakened—or, as it were, thinned out—by the addition of sand or other ingredient. If, therefore, the strength of the structure is determined as well as the proportion of cement to sand, or aggregate, which is to be adopted, the required strength of the cement may be ascertained—with this proviso, however, that the size, nature, and other properties of the sand or aggregate will materially affect the strength of the structure; therefore, if only an indifferent quality of sand is obtainable, either more cement must be used, or a greater strength demanded. The simpler way, however, is not to specify or ask for a cement which is not usually made; take the ordinary article of commerce, and thin it out with as much or as little sand or aggregate as the requirements of the case demand. The matter of specification is thus reduced to the very simplest form, and the object of the test is to ensure the delivery being in accordance with the ordinary demand.

The only three properties of a cement which it is necessary to know in order to determine its constructive value are:—1st, its fineness; 2nd, its tensile strength; and 3rd, its soundness. Though usually placed in this order, it would be more

rational if their order were reversed, for if a cement is unsound, it is evidently useless, while its fineness and tensile strength merely mean the use of so much more or less sand. Taking these, however, in the order in which they are here placed, the author will consider—first, fineness. A mortar or concrete is composed of a certain quantity of inert material called "aggregate," which is bound together by a cementing material, the "matrix," and it is evident that, to secure a sound mortar or concrete, it is essential that each piece of aggregate shall be entirely surrounded by matrix, so that no two pieces are in actual contact. It is hardly necessary to explain that the finer a cement is ground the greater surface will the same weight cover, so that the finer a cement is ground the more economical will it be to use. But there are other reasons why it should be well ground. Cement, until ground, is a mass of partially vitrified clinker which is not affected by water, and which has no setting powers; it is only after it is ground that the addition of water induces crystallisation. It therefore follows that the coarse particles in a cement have no setting power whatever, and may for practical purposes be considered only as so much sand, aggregate, or practically an adulterant. So far, therefore, it appears that an impalpable powder should be asked for; but here the question of cost and economy steps in. The manufacturer will say that it is possible to grind cement to any degree of fineness if paid for, but there is a degree of fineness which is economical, i. e. when it becomes cheaper to use more cement in proportion to the aggregate than to pay the extra cost of additional grinding. With present appliances and means of grinding, that point is, in the author's opinion, reached when the cement is ground to such a degree of fineness that when sifted through a sieve having 2500 holes (50 by 50) to the square inch, it shall leave a residue of not more than 10 per cent. by weight. Cement ground to this fineness will leave from 19 to 21 per cent. of residue on a 4900 (70 by 70) sieve, and practically nothing on a 625 (25 by 25) sieve, and most manufacturers grind now to that degree of fineness.

Secondly, tensile strength.—It would be useless to recapitulate the numerous experiments as to the strength of cements which have been made from time to time by the author and others, and published in the proceedings of this and kindred institutions. The deductions which have been arrived at by an examination of these tests are that the quick-setting cements and those which acquire great strength in a short time, or within the limits of a test, do not, as a rule, continue to increase in strength after a few months, and that after they have attained their ultimate strength they have a tendency to fall off. The extent of this

depreciation has not been conclusively proved, but it is evidently not desirable to use a material which may after a lapse of time seriously deteriorate in strength. It is better to use a cement the strength of which is somewhat less at the early dates, but which it is known will continue to increase for an indefinite period. Such a cement is secured when it is slow-setting, and when tested at different dates shows a marked increase in strength with the age of the briquettes. It was formerly the practice to demand the strength of a cement at the expiration of twenty-eight days from gauging, but such a lapse of time is impracticable, because in most cases the cement would be in use before its strength was ascertained. The author has, therefore, entirely abandoned it except as a corroboration of an opinion formed by tests at shorter dates. Seven days is, as a rule, the limit of time available for carrying out a test, but the strength at only that date would not enable a definite conclusion to be arrived at as to the value of the sample, and it is therefore desirable to carry out a test at an earlier date. Three days is customary, and the ultimate strength of the cement is judged by the increase in strength between those dates. Experience shows that a cement need not have great strength when only three days old, but that it should show a marked increase between that and the seventh day's test. At the same time, in order to secure a material which will be capable of exerting, or rather of acquiring, a certain strength in a fairly short time, a minimum strength at both dates must be specified. The author is of opinion, and he is well supported in it, that a cement should carry at least 175 lb. per square inch at the three days' test, and should show an increased strength of at least 50 per cent. at the seven days' test, but that the minimum strength at seven days should be 350 lb. per square inch.

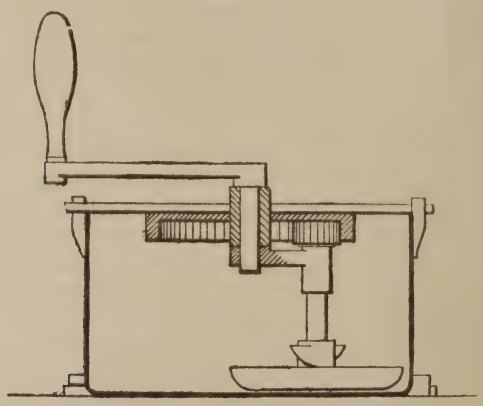
These strengths, of course, refer to the cement when gauged and treated in the ordinary manner, the briquettes being of the most approved form to resist a tensile strain. The form shown in Fig. 2, which gives the best results and is, so far as its form to resist a tensile strain is concerned, that designed by Mr. Grant, of the Metropolitan Board of Works, although it is slightly varied in other respects. Independently of the form of the briquette, there are several other points which will materially affect the results obtained; and though it is hardly within the province of this paper to give a full description of the means of gauging cement, still it would be incomplete without referring to them. They are—The amount of water used in gauging; the expedition with which the gauging is accomplished and the briquette formed; the time which is allowed to elapse between the gauging of the briquette and placing it in water; and,

lastly, the rate of speed at which the strain is applied to the briquettes when being tested.

There is no doubt that a briquette which is put in water directly it is set will show a greater strength than if it is left in the air for a considerable time. But in adopting this practice it is difficult to decide the exact time when a cement is set, and if put in water too soon the strength is deteriorated For this reason, and to secure uniformity in procedure with all cements, whether quick or slow setting, it is usual to place the briquettes in water twenty-four hours after they are gauged.

The second point really means skill in gauging, as it is evident that anyone accustomed to the work will be able to bring the cement to a proper consistency with less water and in a shorter time than a novice, and the less water used, and the quicker the operation is performed, the better will be the results. To obviate this difficulty as far as possible, the author some years ago devised a small machine (Fig. 1), in which to

Fig. 1.



gauge cement, and he has since used it continuously. It is extremely simple, and consists of a stirrer revolving round its own axis in one direction, and round the pan in the reverse. To use it, a weighed quantity of cement is placed in the pan, and the exact quantity of water (which by previous experiment that particular sample of cement has been found to require) is put in at once, and the handle turned until the cement is reduced to the proper consistency. It is then turned out of the pan on to the gauging slate and beaten up with the trowel into a convenient form, and placed in the moulds, when it is lightly rammed and shaken so as to remove all air bubbles, smoothed off on the top, and not touched again until the next day;

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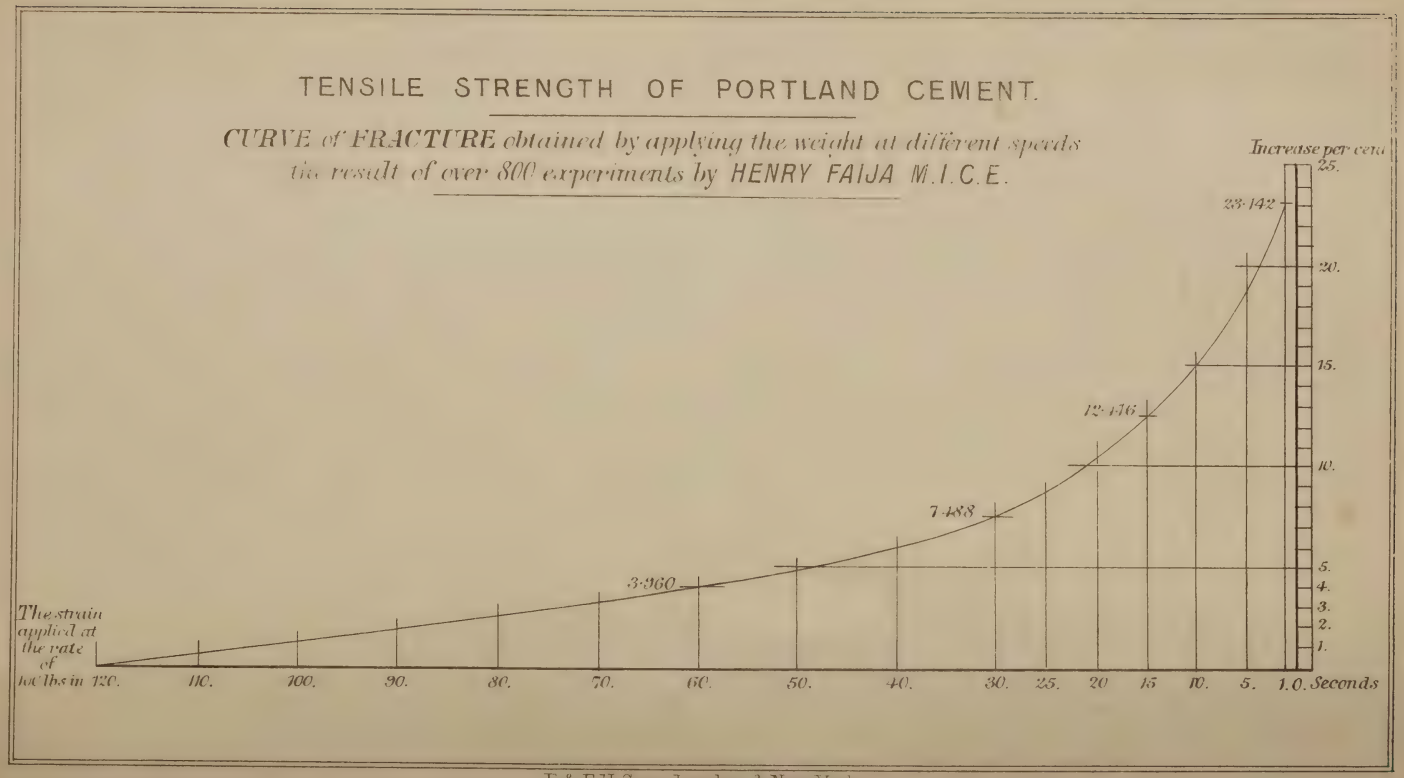

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each briquette is then marked and dated, taken out of the moulds, and placed in water, where again they are not touched until they are to be tested. In determining the strength of a sample it is well to take the average of five briquettes at each date, as from unforeseen causes one might not fairly represent the strength of the cement, and, with this object, it is well to have the moulds arranged in nests of five.

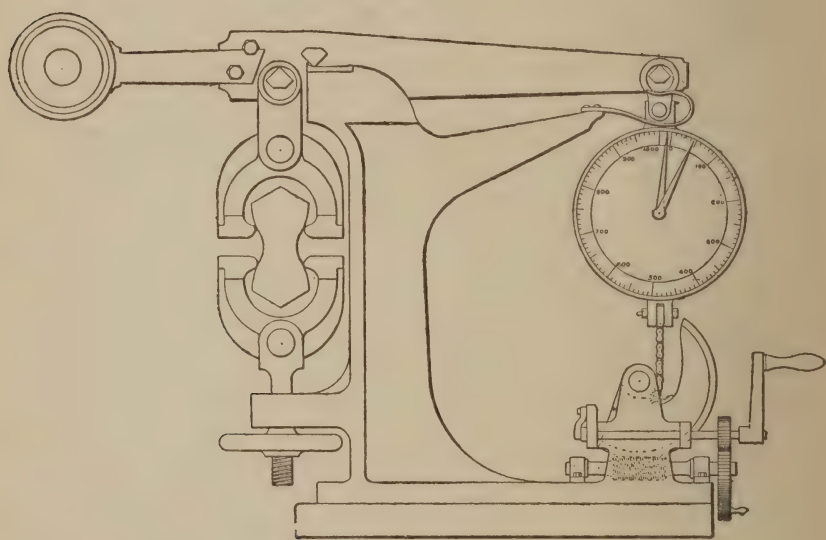
In a paper which the author presented to the Institution of Civil Engineers last year, and which was published in their *Proceedings*, vol. lxxv., he gave the results of a large number of experiments he had made, with the view of determining the variation shown in the strength of a cement, due to the difference in the speed at which the strain was applied, and within the limits at which it would in practice be possible to apply the strain—viz. 100 lb. per second, and 100 lb. per 120 seconds. There was a difference in favour, of course, of the quicker rate, of more than 23 per cent. The annexed diagram is reprinted, by permission, from the above-named *Proceedings*. Without claiming any very great sagacity for carrying out this experiment, for in testing other materials the rate of speed is specified, the author believes he was the first to carry the matter out to a practical issue, for though some thought the strain should be applied quickly, and others slowly, there seemed no very clear idea of what was slow and what was quick. In order to arrive at a happy medium in this respect, the author is of opinion that a rate of speed of 100 lb. per 15 seconds is a fair one. It is one he has used for a number of years, even before he made the above-mentioned experiments, and he sees no reason to alter it. Of course any speed may be adopted, but if the usual speed—i. e. 100 lb. per 15 seconds—is not intended, the speed required should be mentioned in the specification.

The testing-machine designed and used by the author is shown in Fig. 2.

With regard to the third point—soundness of the cement—it is to be observed that, naturally, if a cement is not sound—if it contracts or expands, cracks, or what is called "blows," it is absolutely useless, and it is desirable to determine in as short a time as possible whether or not a cement possesses this characteristic. Because a cement carries the required strain at the three and seven day's test, it should by no means be assumed that it will not blow. Many cements are slow in developing this characteristic, and may even carry through the twenty-eight day's test successfully and blow after that. It is usual to make pats of cement on pieces of glass, or other non-porous material, to place them in water directly they are set, and examine them each day and see if any cracks show themselves

first of all round the edges. Now, with all deference to those who carry out this experiment, the author regrets to say that he has never been able to arrive at any satisfactory conclusion from the examination of the pats. If the cement is really a blowy cement, the briquettes will develop the cracks as well as the pats, and therefore the pats are of no use; if the pats blow and the briquettes do not, and carry the desired strain when tested, the inference is that the pats were put in the water too soon, and before they were set, and thus the blowing is accounted for. Cements vary so much in their behaviour when placed in water before they are set. A slow-setting cement, which would generally be a well-made one, will fall entirely to pieces

Fig. 2.



if put in water before it is set, and will afterwards harden up in the form in which it has fallen, while a quick-setting one, i. e. an overclayed cement, will set quicker and harder if put in water immediately on being gauged; in fact, many cements may be gauged and made up into a ball and put in water at once, and will not alter in form nor disintegrate in the slightest degree, but will harden up as quickly or even more quickly than if left in the air. To get over these difficulties the author uses in his testing-room an apparatus by means of which he is able to determine the soundness of cement in twenty-four hours or even less. He brings it forward with some diffidence, for the

reason that though he has used it now continuously for some years, and has never been wrong in an opinion formed by its indication, in the hands of the unskilful or careless much harm might be done, and many good cements condemned; in fact, it is more suited to a laboratory than to a testing-room.

It is well known that a moist heat is conducive to, and accelerates, the setting of cement. A dry heat, although it may make a cement set quicker, is not beneficial, because it tends to make it friable by removing from it the water which is required for its perfect crystallisation. When a cement is set it may be materially hardened by immersing it in a warm silicious bath, and the combination of the moist heat and the warm silicious bath has formed the subject of a patent by the author for accelerating the hardening of concrete. Now, the author's method of determining the soundness of a cement is based on the theory that, by accelerating the setting and induration of a sample, all its properties, good and bad, are developed in a short time, and hence the result, which, in the ordinary course of things, would not be known for, at all events, some days, and it might be weeks, is determined and ascertained in a comparatively short time. Following out this idea, the apparatus was designed: it consists of two vessels, the one inside the other, the annular space between the two being filled with water, which tends to maintain the inner one, which may be called the working vessel, at a fairly even temperature. Underneath is arranged a lamp or gas burner, which is so regulated that the water which fills the working vessel is maintained at an even temperature of about 110° Fahr. Inside the working vessel, above the water line, are arranged ledges, on which the pats of cements are placed directly they are gauged, the slight evaporation from the water tending to keep the upper portion at a moist temperature of about 95° Fahr. A thermometer is placed in the water, and projects through the cover, so that the temperature may at all times be ascertained. It is also usual to insert a maximum thermometer, so that any undue increase in temperature through varying pressure of the gas may be ascertained. If, during the night or temporary absence, it is found that the temperature of the bath has risen above 120°, the fact of a pat having blown is not taken as an indication that the cement is unsound, but that excess of heat has been the cause. Hence the diffidence of the author in placing the apparatus in unskilled or careless hands. Any sound cement treated in this manner will stand 120°—some much more, even as much as 140°; but many really unsound cements will stand 100° to 105° for the twenty-four hours without showing decided signs of blowing. The steamer, as it is called, for want of a better and

more appropriate name, having been started and regulated, the pat of cement on a glass slab is placed on the rack directly it is made, where it is left for four or five hours. The exact time is not of much importance, but the pat should be perfectly set. It is then taken off the rack and put in the warm water underneath, where it is left for about twenty-four hours from the time of its being made. If it is then still hard and tight on the glass there is no doubt that the cement is perfectly sound; if even it is off the glass but presents a smooth glazed surface, the cement may be considered sound. If, having left the glass, it is cracked on the under surface, the cement is looked upon with suspicion and another trial is made, as the seeming unsoundness of the pat may possibly only be due to the extreme freshness of the cement. If the pat is thoroughly blown there is not much to say in favour of the cement.

The specification which is deduced from the foregoing remarks is extremely simple, and is as follows:—

1. *Fineness.*—To be such that the cement will all pass through a sieve having 625 holes (25 by 25) to the square inch, and leave only 10 per cent, residue when sifted through a sieve having 2500 holes (50 by 50) to the square inch.

2. *Soundness.*—That a pat made and submitted to moist heat and warm water at the temperatures and in the manner already described, shall show no signs of blowing in twenty-four hours.

3. *Tensile strength.*—Briquettes which have been gauged, treated, and tested in the prescribed manner shall carry an average tensile strain without fracture of at least 175 lb. per square inch at the expiration of three days from gauging, and those tested at the expiration of seven days from gauging shall show an increase of at least 50 per cent. over the strength of those at three days; but the briquettes broken at the seven days' test shall carry an average tensile strain without fracture of at least 350 lb. per square inch.

Such a specification meets all requirements, and satisfies the peculiarities of nearly all cements, except perhaps the very quick-setting ones, for which a slight variation in the tensile strength and the percentage of increase between the dates named would have to be made.

The present paper would hardly be complete without a few remarks as to the manner of taking samples for testing. There are certain precautions to be observed, as well in the interests of the user as in those of the manufacturer, and it is always desirable, in order to avoid a multiplicity of tests, to obtain a fair sample of the whole delivery. If the sample is taken from bulk in the manufacturers' warehouse, at least

seven or eight samples should be taken from each 100 tons. They should be taken from different parts of the heap, and not from the surface or outsides, but from about a spit down. These should be taken to a clean part of the warehouse floor and thoroughly mixed by being turned over and over with a shovel, and sufficient of this (about 10 lb. is enough) should be taken for testing. If in barrels or sacks, one or two samples should be taken from each hundred and mixed in the same way. The samples in this case should be taken well from the centre of the barrels or sacks, as the outsides may have been damaged by exposure or other causes over which the manufacturer has no control. Samples in this way should be taken from about each 100 tons and tested separately. It is always desirable when time permits, and especially when sampling from bulk, to spread the cement out on a tray for a day or two to allow it to cool before commencing the test. Theoretically a Portland cement may be used directly it comes from the millstones, but in practice this is not found to be the case, hot fresh cement being always more or less dangerous to use, and the remark that applies to the cooling of the sample previously to testing also applies to the treatment of the cement before using it. As soon as it arrives at its destination let it be turned out of the sacks or barrels on to a cool and dry warehouse floor, and there let it remain as long as possible, turning it over occasionally. Unless it gets wet or damp, it will not deteriorate in quality, but will improve. It may perhaps be said that the manufacturer should deliver the cement properly cooled and fit for use, but independently of the purely commercial reasons which suggest to the manufacturer the advisability of not keeping too large a stock, the amount of warehouse space which he would require if this were the practice would be out of all proportion to the size of the rest of the works.

In the early part of the paper the author used the word "adulterant" when referring to the coarse particles of a cement. He refers to it again because the Cement Makers' Union in Germany has lately had a paper submitted to it, being the result of certain experiments by Dr. Fresenius, made with the object of deciding whether or no a cement is adulterated. Dr. Fresenius says that cement has lately been much adulterated with a material so similar to what cement should be that even chemical analysis fails to detect it, and he therefore submits to the union a number of tests, or rather chemical processes, by which such adulteration may be detected. The author is glad to say that in his practice he has never yet met with an adulterated English cement, any short-

comings in a cement having been due in all cases to more or less faulty manufacture, or to the use of improper raw materials. As every matter of chemical research, or it may be said of testing, connected with cement which emanates from Germany has great weight with many in this country, the author thinks it but right that he should say this much in honour of the English manufacturers who have not had the opportunities of the technical education which is so general in Germany, and which seems, in this particular manufacture at all events, to have enabled the pupil to circumvent the master.

So far as regards these special tests advocated by Dr. Fresenius, the author is not in a position to say whether they are of much value; he is at present trying them in his laboratory, and may be able to say more about them on a future occasion. *Primâ facie*, it would seem that they are not required, for evidently if the adulteration is carried to any great extent, the ordinary tests for tensile strength would detect it. However the user may be quite satisfied that when using English cement he may have a bad or an unsound one, which the tests advocated in this paper will detect, but he is not at all likely to meet with an adulterated one.

DISCUSSION.

The President said that he regarded the paper as a very valuable and interesting one. The use of cement in England and he supposed all over the world, had increased enormously during the last few years. There was no doubt, cement *and* cement, and the material required very careful analysis and testing to ensure its suitability. Cement was always tested for its tensile strength, but its power of resistance to compression appeared to be a point which had escaped the notice of most testers. He thought that it would be very interesting if they could get some information on that point. The slower-setting Portland cements were becoming very important factors in engineering works of the present day. They were largely used for concrete, and in many other ways, instead of lime. There was no doubt that the great recommendation of Portland cement was its property of setting slowly, whereas Roman cement set almost before it could be used.

Mr. T. M. Rymer-Jones said that he had made a series of tests of cement, for resistance to compression as well as to tension, and had gone further, by keeping the briquettes in some of the experiments under water from the first half-hour after mixing until they were tested. Other briquettes were

kept damp and some dry. He considered that a fair way of testing cement which was to be used under water in actual construction. The difficulties of compressive testing lay in the immense force required to crush the briquettes, and in the fact that the resistance did not increase directly as the area, as in testing by tension, but much more rapidly. The ratio of height to base of the blocks experimented on was also of great importance. With regard to the grinding of cement, there was a demand at the present time for a greater fineness than could be easily obtained, and when obtained it not only put the manufacturer to expense, but injured the strength of the cement itself. On other points he perfectly agreed with the paper. He wished to ask the author whether in his tests he took the ordinary size of 1½ inch by 1½ inch, or the 1-inch square section of briquette.

Mr. Faija said that he invariably used the 1-inch square, unless a different size was specially asked for.

Mr. Francis, speaking as a manufacturer, said that he might say that manufacturers in general fully appreciated the great good which papers, like that to which they had listened that evening, did to those who were honestly engaged in producing a good material. They helped to ventilate a subject upon which a great deal of light was required, and also tended to bring into accord the opinions of the engineer and the manufacturer. In regard to the author's suggested specification, he thought that very valuable service had been done in bringing forward the test of soundness. From the manufacturer's point of view, that test was the most valuable of all, and it was the one which should be most carefully adopted. The difficulty which sometimes had to be met was, that the specification required a very high tensile strain. His firm had been asked for as much as 560 lb. per square inch at seven days, and held that such a strain was incompatible with general soundness if taken over a large bulk of material. It was generally admitted that a more moderate test gave a more growing cement, and he considered that a cement which steadily increased in strength and hardness was what was really required. On the other hand, a cement which carried 500 lb. in seven days would have a tendency to disintegrate and go into powder at the end of twelve months. He was glad to see that the author did not attach any importance to the test of weight, and he did not think that any manufacturer was guided by it. As to fineness, his firm had taken the very fine specification of Mr. Grant, of the Metropolitan Board of Works, which permitted only 10 per cent, residue on a sieve of 5800 holes to the inch. They had found this specification very costly to carry out, but if the public was

prepared to pay for it nothing more was to be said. The manufacturer could grind to any degree if he was paid for it. In reference to the President's remark, one reason that the test for compression had not been more frequently used was the difficulty of applying it as compared with that for tension.

Mr. CHEFFINS, of the Gillingham Portland Cement Co., said that he had listened with very great interest to the paper; and he must say that, if all engineers would adopt the specification which the author laid down, manufacturers would be glad to comply with it. Specifications at the present time were so numerous and so various, that no one factory could comply with them all. One engineer would call upon makers to produce a cement of a minimum of 116 lb., and a maximum of 120 lb. Another specification would perhaps require a light, quick-setting cement, intended for a totally different country; and enormous warehouse room would be wanted for the storage of the various kinds. If engineers would only make up their minds to a reasonable weight, say, 112 or 113 lb., they would, he thought, get a very good cement for strain and for fineness, and one which would meet the manufacturers' views. Engineers did not concern themselves about the cost of making, and manufacturers had to stand the racket of all the whims and fancies of the profession. They tried to meet the views of engineers, but he was sorry that they did not always succeed. As to the question of fineness, 25 per cent., on a 1600 mesh was once thought a very good residue. The fineness had now got to be 10 per cent. on a 4900 mesh, but the price had not gone up in proportion. He did not think that the manufacturer had gone very much into the question of compression. The fact was, they had their hands full in the way of tests already. However, he did not want to quarrel with the profession; and he did not think that English cement manufacturers had many complaints made against them. The chief opponents of the English manufacturers were the Germans. The Germans were cutting them out in all the markets, because they were allowed to adulterate their cement. He thought that there ought to be a standard specification, such as the fair and reasonable one which had been proposed in Mr. Faija's paper, and then manufacturers could all work honestly and fairly to it.

Mr. C. HORSLEY wished to know whether the strength of cement increased in regular proportion to the increased area of the section, in the same way as with iron bars. As to tests for compression, they could be compared with one another, if they were always made with blocks of equal size.

Mr. PERRY F. NURSEY said that the sample briquettes exhibited

appeared to vary somewhat in their sectional area at the centre. He supposed it was intended that they should be exactly 1 inch square, but he had found one which measured $1\frac{1}{32}$ inch in depth, though it was exactly 1 inch on the face. This difference of size had suggested to his mind the question whether the tests were carried out with the same accuracy as was observed in the case of tests of iron and steel. He presumed that the cement tests did not run quite so closely into decimals as those of the metals he had named. With regard to testing in compression, he did not see that there need be any difficulty about it, or that it required a very elaborate apparatus. When the Society visited Ransome's Artificial Stone Works at East Greenwich, some eight or nine years ago, he saw a number of tests of the stone carried out, both for compression and for tension. If he remembered rightly, the blocks tested for compression were cubes of four inches. He believed that it had been found, after a long series of experiments at Ransome's works, that cubes of those dimensions gave the fairest average results. Although there might be no difficulty in carrying out tests for compression, there still arose the question of what value they would be. The character of the cement being known, what a given quality of cement would do in practice might generally be fairly assumed; and it generally did a great deal more than was reckoned upon.

Mr. Shadbolt said that he very much approved of what had been stated by the author, and was pleased to hear him say that he did not think that the English manufacturers adulterated their cement. He (Mr. Shadbolt) did not think that they did; but they were often accused of doing so. There was a very simple way of finding out if there were adulteration. It had been said to him sometimes, "You have put in sand." He had replied, "Sift it out, and take the residue, and try it with pestle and mortar, and you will very soon find that the particles which you call sand are the strongest and hardest part of the cement." Compression had been suggested as a test, but he did not think that it was a good or fair one. The best form of the specimen for testing would be a cube, but the consequence of the least irregularity in form would be undue pressure upon one corner or portion of the cube, and that would disintegrate it and thereby break up the cube with a less pressure than if the surfaces were perfectly true. He thought that there could be no better test than the tensile strain, but he should like to see one uniform machine adopted for applying that test. His maxim had always been that any inexperienced person could use the testing machine, but that it required a skilful man to gauge a briquette.

The PRESIDENT, in closing the discussion, said that the subject was a most interesting one, and he believed that the use of cement would increase every day, and would only be limited by the capacity of the manufacturers to produce it, and that if the manufacturers would give engineers good cement, they would be able to use it for still more various purposes.

Mr. FAIJA, in reply, said that he was sorry that the discussion had not assumed a more animated form. He had expected a great deal of opposition, especially from the manufacturers; but he was pleased to find that they agreed with him more than he had anticipated. The President had been good enough to suggest a crushing test. Some years ago he (the author) made a great many experiments in crushing cubes, but he never obtained any satisfactory result. Cubes of the same cement and of the same age, broken under the same conditions, gave very different results. One would break at 2000 lb. and another at 5000 lb. It was not difficult to see that the difference was due to irregularities in the accurate form of the cubes. If unfortunately there was a slight rise at the edge, the cube, instead of receiving the crushing pressure as a whole, would be taken in detail, and as soon as the edges were crushed the whole cube would give way, and no satisfactory result could be obtained. Even placing the cube between soft wood pads did not entirely get rid of the difficulty. Other people besides himself had made experiments in crushing cement, and had failed to obtain the satisfactory results which, *primâ facie*, the test might be expected to give. In addition to this, he thought that it would be a pity to introduce a new test, and supersede that of the tensile strain. If the test of a tensile strain were given up, all the knowledge which had been gained with regard to that point during the last forty years would be lost. It might be added that the crushing strength appeared to bear no definite ratio to the tensile strength. Mr. Rymer-Jones had mentioned some tests which he had carried out upon cement which had been set partly in water and then finished in the air. Tests of that kind were very important, and he would ask that Mr. Rymer-Jones might be requested to furnish the Society with a statement of the results of his experiments. On the subject of adulteration of cement by German makers, Mr. Cheffins had gone a great deal further than he (the author) had gone. Dr. Fresenius had stated that the Germans adulterated with blast-furnace slag, as being a material which was very much like Portland cement in analysis, but which yielded totally different results. He (the author) had last week made an analysis of ordinary furnace slag, and he ascertained the constitution to be 36 per cent. of lime, 34 per cent. of silica, and

26 per cent. of alumina and iron. He thought that all the manufacturers present would agree with him that that would not represent the analysis of a cement. He had an analysis of Bessemer slag; but this he did not make himself, and he was not responsible for it. It gave as much as 74 per cent of silica, and only 2 per cent. of lime. Of course some slags might give an analysis similar to a cement. Dr. Fresenius mentioned other tests; and among them was that of specific gravity. This he stated should very from 3·1 to 3·125. He (the author) was afraid that it would be impossible for any one but an expert analyst to determine the specific gravity to such a nicety. Then there was the loss on ignition, by which was meant a red heat. Dr. Fresenius said that 2·59 per cent. was the maximum which a genuine Portland cement should lose on ignition. In this respect he did not agree with Dr. Fresenius, for a perfectly good cement, air-slaked for six months, might absorb a large amount of carbonic acid and moisture, which it would lose upon calcination. Many cements which were perfectly sound and well burnt, if of any age, would lose 5 per cent. upon being burnt again. Experiments which he carried on some time ago showed that in a perfectly set cement the water of crystallisation was not more than 7 or 8 per cent. Many cements would absorb moisture up to 4 or 5 per cent. without being damaged, after that, they became caked and deteriorated.

The want of uniformity in the briquettes, of which Mr. Nursey had spoken, arose in the trowelling of the briquettes while they were wet. Slow-setting cements would often contract if they were cleaned off level with the edge of the mould; and quick-setting cements would begin to set before they could be fully finished off. The small difference noticed in the briquettes on the table was of no practical importance, for its results were considerably less than the difference (sometimes over 20 per cent.) which occurred between any five briquettes gauged at the same time and treated throughout in the same way, the reason of which was as yet unexplained. One thing was certain, that an air-bubble on the outside of the briquette was more detrimental than a similar one in the centre, and one at the angle would often cause a briquette to break at a very low strain; but beyond this he had never been able to assign the variation to any satisfactory cause.

The 1-inch section was the size of briquette generally used at the present time. Mr. Grant was almost the first in England to adopt it, and he (the author) had followed him. Formerly a section of 1½ inches by 1½ inches was generally in use. As regards the results in testing, there was practically no difference between the two sizes, of course in proportion to the areas—none,

at least, that could be referred to different setting of the cement due to difference of size.

The method which Mr. Shadbolt had described as a test for adulteration would only hold good if the adulterant were coarser than the cement. If it was ground to the same fineness, sifting would evidently not separate the adulterant from the cement.

He wished again to draw attention to the curve given with the paper, which showed graphically the results obtained by applying the strain in testing at various speeds. It was a matter of great importance—perhaps even more so to the manufacturer than to the user. Cement might be condemned really because the strain was applied too slowly; and on the other hand. manufacturers might deceive themselves in testing their own cement, by applying the strain too quickly. The point had not received proper attention up to the present time; but he hoped that before long some recognised speed, such as he had suggested in the paper would meet with general adoption.

THE VACATION VISITS.

During the vacation of 1885, the usual series of visits was made, according to the established custom of the Society, to engineering works in and near London. That the interest of the Members and Associates in these visits continues to be fully maintained is shown by the large numbers that attended on each occasion.

The first visit was, on June 17th, to the Tilbury Docks, in course of construction on the north side of the Thames, opposite Gravesend. In these docks the East and West India Dock Company will provide that deep-water accommodation for steamers of the largest class, which is so much desired. They are being constructed on the designs and under the supervision of Mr. A. Manning and Mr. Donald S. Baynes, the contractors being Messrs. Lucas and Aird.

The whole area now fenced in amounts to about 320 acres, the fencing itself being nearly three miles in length, but the company has also purchased a large plot of land on the west side, which would be available for future extension of the docks. The entrance from the river is 300 feet wide at the narrowest point, and is led up to by two timber jetties projecting into the river at angles of 35°. At the south or river end of each jetty a cast-iron cylinder, 15 feet in diameter, filled with cement concrete, is sunk down to the solid chalk, and forms a kind of boss round which the massive timberwork is built.

The tidal basin has a water area of 19¼ acres, with a depth of 26 feet at low water of spring tides, or 45 feet below Trinity high water.

The main dock lies to the north-west of the tidal basin, and is approached from it through a lock 80 feet wide and 700 feet long, provided with three pairs of wrought-iron gates, which divide it into two lengths of 555 and 145 feet respectively for ordinary use, while allowing of the full length of 700 feet being occupied, if required. The lock-gates are 44 feet high. Their sill level is 44 feet below Trinity high water. They are worked by hydraulic power or by hand.

The main dock is 1664 feet long by 600 feet wide, and has a water area of 23 acres, with a depth of 38 feet from Trinity high water. Out of it there project forwards, towards the north-west, three branch docks, each 1600 feet long, the centre

one being 300 feet wide, and the side ones 300 feet at the south end and about 250 feet at the north, the depth throughout being the same as that of the main dock. The total area of the main dock and branches is 52½ acres.

The quays between the branch docks, 382 feet wide each, carry extensive sheds with ample sidings and every appliance for loading and unloading.

The quay walls throughout the work are of concrete, faced above low water with blue brick and coped with granite. Those on the east and south sides of the tidal basin are provided with half-tide landings and gangways for the accommodation of passengers. The west end of the basin has sloped sides pitched with Kentish rag.

Graving docks are provided, running parallel with the lock, and having entrances at each end, from the tidal basin and main dock. They are 70 feet and 60 feet wide at bottom respectively, and are divided each into two lengths by a caisson at the centre, making four graving docks: By floating out the dividing caissons, docks can be obtained 875 feet long, capable of docking the largest vessels; and through either of the graving docks an additional entrance can be obtained into the main dock, if necessary.

The motive power will be hydraulic throughout the whole of the docks, and the engine-house has been erected at the north end of the branch docks and provided with three pairs of compound-engines and pumps.

Space is reserved for a fourth pair of engines, &c., to provide for future extension of the docks. The accumulator is placed in a lofty tower, connected with the engine-house, the hydraulic pressure throughout the pipes being 700 lb. per inch.

Every part of all the hydraulic work is in duplicate, and so arranged as to guard against the possibility of any of the machinery dependent upon it being cut off from the source of power.

The London, Tilbury, and Southend Railway, running along one side of the dock property, affords convenient railway communication with London, both for passengers and goods, the lines extending to all the quays and landing stages. It is intended to erect large granaries, with hydraulic elevators and every appliance for the grain trade.

On the occasion of the Society's visit, the Members and their friends were received at the Tilbury station by Mr. Donald S. Baynes, M. Inst. C.E., acting as resident engineer, and Mr. W. Colson, A.M. Inst. C.E., the contractors' agent and engineer, by whom and their assistants they were conducted over the works in two parties and every point of professional interest was fully observed.

One subject of especial interest was a large steam excavator, by Ruston and Proctor, and many listened attentively to the opinion as to its merits and its conditions of economy, in comparison with navvies' labour, expressed by Mr. Colson, whose experience is almost unique, as having had the management of several of the largest dock contracts in England during recent years.

There were at the time about 4300 men engaged on the works, and the lines of temporary railway were 40 miles in length. The contractors' plant included 46 locomotive and 19 portable engines, 87 steam cranes, 15 patent pile-engines and 3 steam navvies. The pumping power consisted of six pairs of Rocher pumps throwing in all about 10,600 gallons per minute, two centrifugal pumps throwing 3400 gallons, and two double Woodford pumps throwing 2000 gallons, making a total power of about 16,000 gallons per minute.

The second visit was, on July 8th, to the locomotive and carriage works of the South-Eastern Railway at Ashford. Although these works are necessarily much less extensive than those at Derby, visited in the previous summer, they are very complete, and present points of interest of their own.

The party travelled to Ashford in special saloon and first-class carriages attached to the fast train leaving London at 10.17. On arrival at Ashford station they were met by Mr. James Stirling, M.I.M.E., the locomotive superintendent, and Mr. W. Wainwright, the carriage superintendent, and the special carriages were detached and run on to the works, where a temporary platform had been provided.

Mr. Wainwright then conducted the party through his department, where the entire construction and repair of the company's carriage and waggon stock is carried out. The average quantity of coaching stock on the works, under and waiting repairs and laid aside, is about 200, or 10 per cent. of the total stock; and about the same number of waggons, or 4 per cent. of the total waggon stock. The wood-working machinery is very complete and excellent. The various processes of wheel-making were observed with interest. The wheels are here made of the same size for both carriages and waggons, so that the latter can run at the same high speeds as the former, if required. The discs are of wood, and special means are adopted to secure perfect balancing of the finished wheels, of which about 480 are turned out in the year. Both tyres and springs are also made in the smiths' shop.

Mr. Wainwright next exhibited some invalid chairs, designed by himself and ingeniously constructed for the ease and comfort of suffering travellers, and so formed as to be capable of

being carried bodily into the carriage, thus avoiding the necessity of removal. These chairs readily adapted themselves to the position of the occupant, and were declared by one of the company who tested a finished one, to be most comfortable. After having viewed these, and bestowed well-deserved encomiums on the inventor, the company next examined a complete train of carriages fitted up for service, and provided with means for the supply of gas for lighting during a journey.

In connection with this department, the visitors were shown an interesting relic of past railway practice, in the form of an old composite carriage, which was used by the Duke of Wellington when Warden of the Cinque Ports, and which presents a remarkable contrast to the splendid carriages of the present day. Its total length of body is only 14 feet 9 inches, and width 6 feet 8 inches. The height of the first-class compartment, from floor to roof, is but 6 feet 8 inches, and that of the two second-class compartments only 5 feet 5 inches, while the doorways are not higher than 4 feet 10 inches.

Mr. Stirling then conducted the party through the locomotive works, outside which another railway antiquity was shown, the *Invicta* engine, built by Stephenson, which ran on the Whitstable Railway from 1830 to 1838, a locomotive not dissimilar in appearance to the celebrated *Rocket*. It could then run a load of 20 tons at a speed of 10 miles an hour. In contrast to this relic of the past was Mr. Stirling's latest express engine, with 7-feet coupled wheels and cylinders 19 inches by 26 inches, with his clever reversing gear. This engine has proved itself capable of taking a tidal train and twenty-six carriages a distance of 70 miles in 90 minutes.

The rolling-mill, foundry, fitting and erecting shops were successively visited, after which the visitors were entertained at luncheon by the company, part of the carriage-building shop having been fitted up for the occasion. The special carriages were then run on to Folkestone and Dover, from whence the return journey was made by the evening trains.

The last visit of the year was made, on the 16th September, to the London Yard Engineering Works of Messrs. Westwood, Baillie & Co., Isle of Dogs. It had been deferred to as late a date as possible, that the preparations for the temporary erection of the great cantilevers of the Sukkur Bridge might be seen at advantage. There were other objects of interest on the works but the chief attraction was this important bridge, which is to span the Rohri Pass of the Indus at Sukkur, on the line of railway from Kurrachee to Quetta. It has been designed on the cantilever principle, by Mr. A. M. Rendel, M. Inst. C.E.,

and is similar in general characteristics to the large spans of the Forth Bridge, now being erected, though of much smaller dimensions. It will, however, have the largest clear span of any of the Indian bridges, and will rank among the great bridges of the world. The main span is 790 feet in the clear between the abutments, and the vertical pillars are 820 feet apart, centre to centre. The space between these pillars is crossed by two cantilevers, of 310 feet each, connected by a girder bridge 200 feet in length. Each cantilever springs from a pair of framed and braced pillars, 174 feet long, vertical on the side elevation, but inclining transversely towards each other. From the same base plate as these pillars there rise a pair of raking struts connected with them at top by horizontal ties, which carry on the tension from the inclined ties stretching to the end of the cantilever to those over the land which terminate in the anchorage. Other members form a huge bracing, transmitting the internal stresses of the cantilever finally to the same base plate. The girders carrying the roadway, which form the compressional members of the cantilever for more than half its length, are 40 feet above the level of the base plate, down to which the compression is carried by inclined struts leaving the horizontal at about 110 feet from the pillars.

The material throughout is to be of steel, of which about 3200 tons will be used in the cantilevers alone, exclusively of the 200-feet girders. The whole of the steel is being supplied by Messrs. J. and W. Beardmore, of the Parkhead Forge, Glasgow. It is of high quality, having to pass the following tests. All plates, either with or across the grain, L, T, or flat bars must bear a tensional strain of not less than 27 or more than 31 tons per square inch, with 30 per cent. contraction of area at the point of fracture: and all rivet rods not less than 25 or more than 28 tons, with 40 per cent. contraction. Besides these, severe bending tests are specified, and it is stipulated that the tensional test is to be applied to every steel plate used in the work, and shearings are to be kept, and marked, from every plate and bar, for subjection to the bending tests.

Each cantilever has to be erected in the contractors' yard before being shipped for India, which condition has necessitated the erection of a massive staging, of itself an object of professional interest and the result of careful study. This staging, which will require over 2000 loads of timber, covers an area of 400 feet long by about 120 feet at the greatest width, and will be 180 feet high. It was partially erected at the time of the Society's visit, and some of the most massive parts of the bridge itself were in course of preparation, including the anchor-plates,

20 ft. by 6 ft. by $1\frac{1}{4}$ in., each weighing 2 tons 14 cwt., and the bed plates, 22 ft. by 5 ft. by $1\frac{1}{4}$ in., each weighing 2 tons 10 cwt. The work of planing and drilling these large plates was of great interest, as were other processes, such as that of stamping the heavy corrugated flooring plates, which are a speciality of the firm, and which are to be employed in the construction of the Sukkur Bridge, and others for the Indian State Railways.

The Members and their friends were conducted over the works by Mr. J. R. Baillie and Mr. W. Parsey, the chief of the staff. Mr. F. E. Robertson, A.M. Inst. C.E., who will have charge, as resident engineer, of the erection of the work in India, was also present, and courteously assisted with information. The original and working drawings, very numerous and complicated, were displayed for the inspection of the visitors on a long range of tables in the moulding shed, and their comprehension was greatly assisted by a large model of a cantilever complete.

The interest felt in observing the early stages of this important work was greatly enhanced by the announcement that Messrs. Baillie purpose inviting a similar visit of the Society in 1886, when one of the cantilevers is completely erected on the staging.

October 5th, 1885.

CHARLES GANDON, PRESIDENT, IN THE CHAIR.

OPENING BRIDGES ON THE FURNESS RAILWAY.

BY CHARLES J. LIGHT.

IN the following paper the author is desirous of bringing before the Society two opening bridges of very different types, but each possessing, he believes, novelty both in principle and construction. They were both designed under the instructions of Mr. F. C. Stileman, M. Inst. C.E., for the Furness Railway; the one in connection with the Barrow Docks, and the other for the Bardsea branch of that railway.

THE BUCCLEUCH DOCK BRIDGE.

The Buccleuch Dock Bridge spans a water passage, 80 feet in width, between the Buccleuch and Cavendish Docks. It carries the main line of railway to the Dock Station, and has also a carriage way and two footways. It is a double-leaf swing bridge, but its special peculiarity is that, between each leaf and the pivot on which it swings, is interposed a pair of spring girders. These support it freely on the pivot when unloaded, but yield to the increased pressure caused by an advancing load, and allow the bridge to come down and rest on bearings placed close to the coping of the passage wall. Not only is a rigid support thus obtained for the bridge when loaded, but the span is reduced to a minimum.

A brief account of the designs proposed before this was finally adopted may be of interest, as giving some further reasons for its selection. It was originally intended to provide for the railway and two footways only, and the first design was for a traversing bridge. Its length would have been 150 feet, and estimated weight 120 tons, with 34 tons counterbalance, making in all 154 tons, to be lifted 28 inches and traversed 84 feet. A single-leaf swing bridge was then considered. Its

length would have been about 160 feet, and weight about 127 tons, with 46 tons counterbalance, making in all 173 tons. This was open to objections—1st. That on account of the confined width of the quay, it would have projected too far over the dock, when the bridge was opened; and, 2ndly. Excessive pressure must have been thrown on to the forward rollers, or the strength and weight of the bridge must have been largely increased to distribute the pressure equally amongst the rollers.

A double-leaf swing bridge was therefore decided upon, and provision had to be made for the addition of a carriage way. The outside width of the bridge was consequently increased to 31 feet. This necessitated an increased distance between the pivots, and the whole structure became larger and heavier. The author then suggested the adoption of spring girders, a system which had once before been employed in the case of the swing bridge carrying a line of railway over the entrance to the North London Railway Company's dock at Poplar. The idea of the spring girder was originated by Mr. James Campbell, of the then firm of Westwood, Baillie, Campbell & Co., who built the bridge for the North London Railway, and for whom the author superintended the testing of the spring girder and the construction of the bridge generally. In this instance the span of waterway was 50 feet. The bridge was a single-leaf bridge about 40 tons in weight, with bearings in line with the pivot. At Mr. Stileman's desire the author examined this bridge, which had then (November 1877) been erected about fifteen years, and he ascertained from those in charge that the spring girder continued to act perfectly, and that the only defect was the small size of the pivot, which had consequently worn down much and allowed the bridge to touch the bearings, causing great increase of friction. Notwithstanding this, one man was able to swing the bridge by the hand gearing provided. This inspection satisfied Mr. Stileman that, with improvements suggested by the experience of the Poplar bridge, a safe and easily worked bridge could be designed for the Buccleuch Dock. Indeed, the double-leaf construction afforded still greater facilities for the use of the spring girder system, as, by means of a simple key at the meeting, both leaves would rise and fall together according to the deflection of the spring girders, the rails at both ends of the bridge being always level with those on the quays.

The next important question was the nature of the anchorage or counter-balance required to support the overhanging load when between the bearings. There were three alternative modes of dealing with this, namely:—

1. By adding sufficient kentledge at the tail ends to counter-

balance, not only the bridge itself, but the live load when covering the length between the bearings. It was estimated that for this 50 tons would be required at each tail end. The objections were that this mode limited the live load, and the friction was great, requiring a power of 1620 lb. at 31 feet from the pivot.

2. By carrying the upward pressure at the tail ends by rollers working under a kerb-ring anchored to the masonry. In this arrangement no kentledge would be required on the bridge, nor would the live load be limited, but the friction necessarily remained as high.

3. By employing only sufficient kentledge to balance the dead-weight, with some addition for steadiment, and carrying the upward pressure due to the live load, by means of keys at the tail ends of the girders, to an anchorage in the masonry. This arrangement reduced the power required to 664 lb.

The first method was entirely unsuitable, for, on calculating the strains in the girders, it became evident that, owing to the peculiar action of the spring girders when the bridge was loaded, a further 38 tons of kentledge would have been required at each tail end, increasing the power required to turn each leaf to 3300 lb. The second method would not have been thus affected, but the third obviously met all requirements best, and had the great advantage of only requiring a power of (on the final revision) 645 lb. The general conditions having now been decided, the design, as afterwards executed, was made to the following general dimensions:—

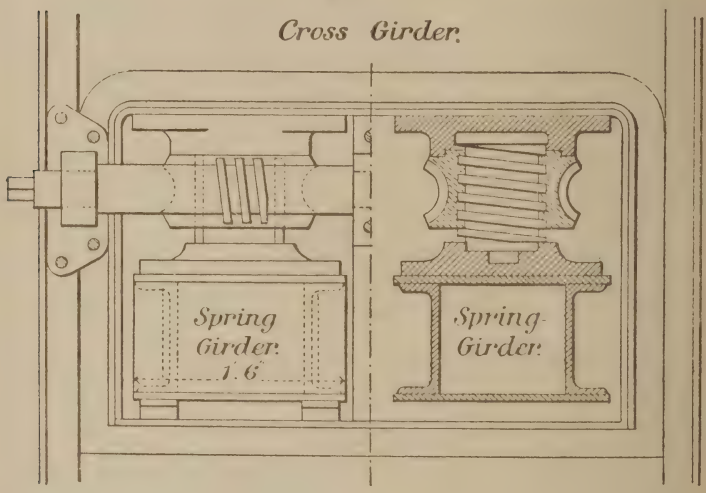
	Feet.	Inches.
Total length of the bridge	173	6
Total width	31	0
Clear breadth of waterway	80	0
Distance centre to centre of bearings	85	6
Ditto ditto pivots	110	6
Radius of meeting face	55	9
Radius of tail end	31	6

Each leaf consists of three longitudinal girders, connected by cross girders 8 feet 4 inches apart, and having cantilevers on the outer sides to carry the footways. The two main girders A and B, carrying between them the railway (see Plate I.), are 14 feet apart centre to centre. The third girder, C, is under the carriage way, and 7 feet centre to centre from B. All three girders are of an open-web pattern, as shown on the elevation. Girders A and B are 7 feet deep to the backs of the L irons, and rise 1 foot 9 inches above the floor, thus forming also kerbs for the traffic. Girder C is 4 feet 9 inches deep, and covered by the flooring of the carriage way. Beyond the bearings the girders are all gradually reduced in depth, till, at the

meeting faces, A and B are 3 feet 9 inches deep and C 1 foot 6 inches deep.

There are four rails laid across the bridge to lead without facing points on to the two lines of way at each end. The rails are of the bridge section, on hard wood packing 5 inches thick, laid crosswise, and resting on four lines of rail bearers riveted between the cross girders. The floor between the main girders is of 3-inch deals, and that of the carriage way is of 4-inch planking laid longitudinally, with boards 1 inch thick spiked

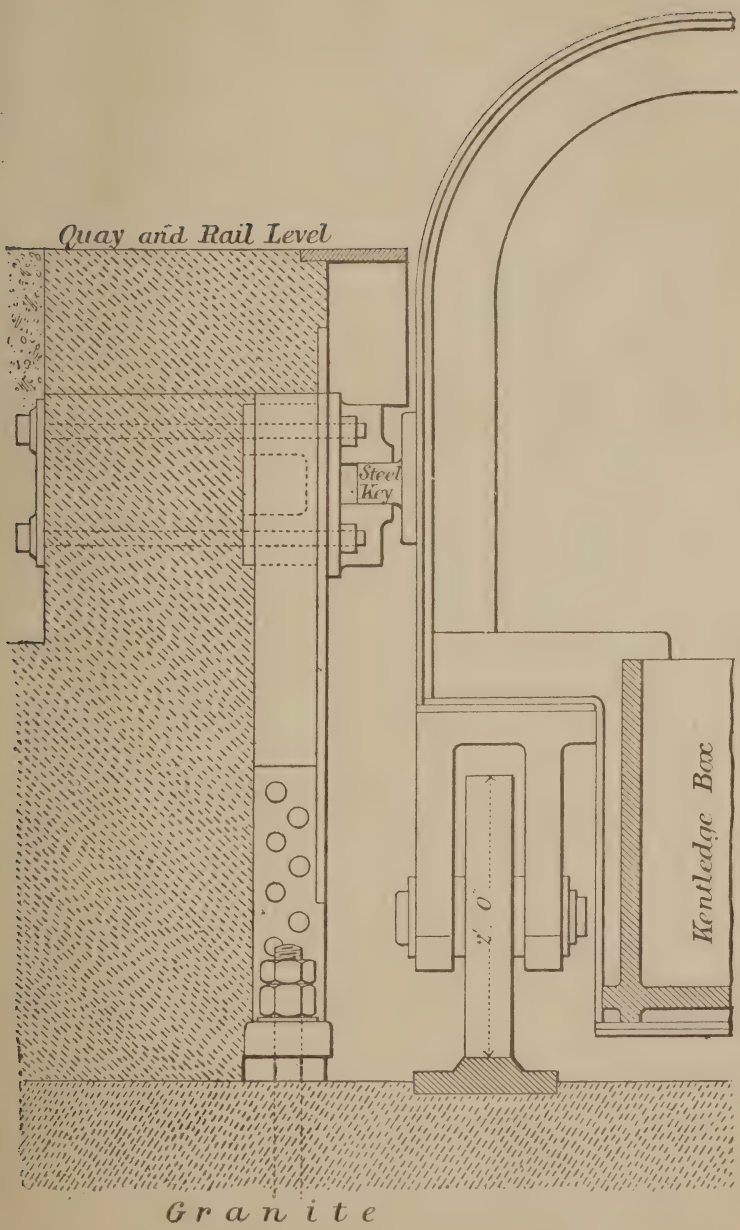
Fig. 1.



down upon it to take the wear of the wheels. The footways are laid with 3-inch deals. All Memel timber used is creosoted. The special construction connected with the spring girders is as follows:—

The two cross girders at 12 feet 6 inches each way from the pivots are made of extra depth and strength, as shown on the longitudinal and transverse sections (Plate II.), to receive the weight of each leaf and transfer it to the ends of the spring girders. These ends pass through openings in the special cross girders, which bear upon them through the intervention of adjusting apparatus (Fig. 1), by means of which the respective proportions of load to be brought on to each end of each spring girder can be adjusted to the greatest nicety. The value of this arrangement was fully shown during the erection of the bridge. There are two spring girders to each leaf, it not only being found desirable to divide the heavy load, but the division

Fig. 2.

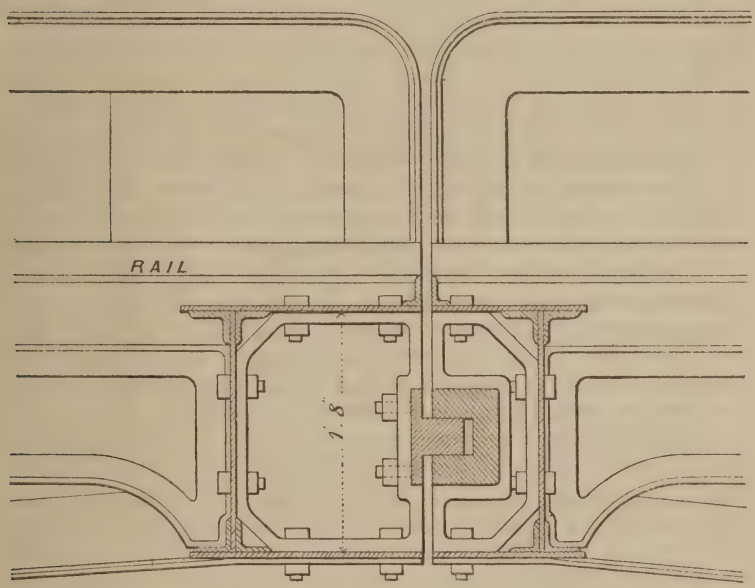


greatly facilitating the adjustment and balancing of the bridge. Each pair of spring girders rests upon a cast-iron pivot-cap, within which is a steel bolster, which turns on the convex steel head of the pivot 20 inches in diameter. The body of the pivot is of cast iron, spreading out into a circular foot 4 feet in diameter, which is bedded on and bolted down to a granite block 5 feet square, built into the sandstone masonry. The bearings are of cast steel bolted to the under side of the longitudinal girders at 12 feet 6 inches from the centre of the pivot, thus reducing the bearing span, when the bridge is loaded, by 25 feet. Underneath them, with a free clearance when the bridge is unloaded, are bearing-plates of wrought iron, planed on both faces and keyed into cast-iron bed-plates partially let into granite blocks which form part of the coping of the passage walls. The provision for taking the upward pressure at the tail ends consists of a slightly tapered steel key, riveted to the end of each of the longitudinal girders and fitting into a groove on a cast-iron plate on the vertical face of the fixed kerb (Fig. 2). These castings are bolted through the masonry of the kerb wall, but are held down by heavy straps or stirrups of L iron, which are in turn connected by holding-down bolts 2½ inches in diameter to anchor plates 4 feet by 3 feet laid under masses of granite masonry at each end of the bridge. The maximum lifting stress at each end is 54 tons. At the meeting face the two leaves are bonded together by a tapered key of wrought iron 22 feet long, curved and planed to the radius of the convex face and secured to the last cross girder on the southern leaf by means of five small cast-iron brackets, as shown on the longitudinal section of the bridge (Plate II.), and in detail, Fig. 3. This key fits into a cast-iron groove of corresponding length and taper, similarly attached to the last cross-girder on the convex side. The keys secure the whole bridge vertically, and locking bolts connected with the signals each way secure its being in true position horizontally. Owing to the unsymmetrical transverse section of the bridge, the pivot is 4 inches out of the centre of the width, on the carriage-way side.

The parts that require detailed notice are the spring-girders, their testing and adjustment. The rest of the work has no special features, except that the stresses in the longitudinal girders are greatly affected by the reaction of the spring girders, when the bridge is loaded. To obtain the necessary condition of great elasticity the spring girders have to be of abnormally small depth in proportion to their length, and therefore present points of great interest as examples of stress and deflection carried to an extreme. The mode of calculating their proportions was as follows:—The clearance at the bear-

ings when unloaded was fixed at $\frac{1}{4}$ inch. The distance from the tail key (which acts as the hinge) to the pivot being 31 feet 6 inches, and to the bearing 44 feet, the increase of deflection in the spring girders, corresponding to the descent through the 0·25 inch clearance at the bearings, is 0·18 inch. It was assumed that this increased deflection, or, in other words, the bridge coming down to its bearings, should be effected by a live load equivalent to 10 tons over the pivot. As this was divided between the two spring girders, it resulted that 5 tons must

FIG. 3.



produce a deflection of 0·18 inch or 0·036 inch per ton of load. It was further decided to use Bessemer steel for the top and bottom plates, and to work up to a stress of 15 tons per square inch under the maximum load. This was adopted in consequence of the successful experience at the Poplar bridge, where wrought iron had been employed at a stress of 10 tons per inch. The maximum load on each spring girder would be:—

Dead load	55 tons
Proportion of live load, as above	5 „
Maximum load when the bearings touch	60 „

Deflection under this load 60 × ·036 = 2·16″
Length of span .. .. 25′ = 300″

The constant of extension was assumed at $\frac{1}{15000}$, the same as the author has been accustomed to use for wrought iron; it being uncertain how steel would behave under the extreme conditions: e therefore was $\frac{15000}{15} = 1000$.

Then $h = \frac{l^2}{4ed} = \frac{300^2}{4 \times 1000 \times 2 \cdot 16} = 10 \cdot 4$ inches = effective depth required.

It was then decided to use for the webs two channel irons $9 \times 3\frac{1}{2} \times \frac{1}{2}$, connecting them to the top and bottom plates by 1-inch steel rivets, 3 inches apart centre to centre. This close and heavy riveting was rendered necessary by the great shearing stress, viz. 30 tons throughout the whole length of each girder, or 15 tons to each channel iron.

The analysis of the riveting gives $15 \div$ No. $3 \times 1 \times 0 \cdot 5 = 10$ tons per square inch bearing stress; and $15 \div$ No. $3 \times \cdot 7854 = 6 \cdot 4$ tons shearing stress.

For the net area of top and bottom flanges,

$$\frac{25 \times 60}{4} = \frac{10 \cdot 4}{12} \times 15A$$

$$\therefore \quad A = 29 \text{ square inches.}$$

The top and bottom plates were all 18 inch $\times \frac{1}{2}$ inch, arranged thus:—

	No. 4 plates to	4 feet from centre;
thence	3 plates to	7 feet ,,
	2 plates to	10 feet ,,
then	1 plate to the end.	

The net maximum section was therefore—

$$(18-3) \times 2 = 30 \text{ square inches.}$$

(There are four rows of rivets, but as the two central ones alternate in pitch with the outer ones, the loss of width is as nearly as possible = 3 rivets.)

Especial care was taken in specifying the mode of manufacture and testing for the spring girders, and one was made and tested before proceeding with the rest so as to verify the calculations. The detail of the tests will be given further on, but the general result was so satisfactory that no change whatever had to be made, and the other three girders were built to the same pattern. The testing was carried out by Mr. Frank Stileman, the resident engineer of the docks, and the pressures, applied by hydraulic ram at the centre, were successively 32, 42, 52, and 62 tons by gauge. The final test pressure of 70

tons was then applied, and repeated until the permanent set was fully obtained. Each of the four spring girders was subjected to this process, the object of which was not only to prove the quality of the materials and workmanship, but to ensure the girders taking their final camber before being fixed in place.

The modifications of the original calculations were as follow:—It appeared that the steel was stiffer, as had been expected, and that the constant of extension should have been $\frac{1}{18000}$ instead of $\frac{1}{15000}$, the deflection per ton of load being 0·030 inch instead of 0·036. The actual mean effective depth was 10·25 inches, and the dead load, it was found, would be 56 tons per spring girder, or 1 ton more than assumed in the first calculation. These differences balanced one another. In testing the spring girders advantage was taken of the experience gained in the case of the Poplar bridge, and it will probably be interesting to compare the two series of tests, remembering that in the earlier instance wrought iron was used, and in the later, steel.

TESTS OF SPRING GIRDER (WROUGHT IRON) FOR BRIDGE AT POPLAR DOCK, MAY 1862.

Tons Pressure on Gauge = say, net.	20 18·5	30 28	35 32·5	40 37
Deflection	1·7	1·9	—	—
Set	1·1 0·032	0·85 0·037	—	—
Deflection	—	1·35	—	—
Set	—	0·27 0·038	—	—
Deflection	—	1·2	1·5	—
Set	—	0·03 0·043	0·25 0·038	—
Deflection	—	—	1·5	2·1
Set	—	—	0·10 0·043	0·55 0·042
Deflection	—	—	—	1·75
Set	—	—	—	0·20 0·042
Deflection	—	—	—	1·63
Set	—	—	—	0·08 0·042

The positions of the figures show the successive applications of pressure. The vertical figures show the net deflections per ton of net pressure. For comparison of this table with the following one, it may be observed that the theoretical ratio of the deflections per ton of load would be directly as the square of the span × the maximum stress (in tons per inch) allowed, and inversely as the effective depth × the maximum load × $\frac{5}{6}$

(the ratio of extension of iron to that of steel), or as 3·18 to 2·35. The deflection per ton of load in the Poplar girder being 0·042, that in the girder for Buccleuch Dock Bridge would be, theoretically, 0·031. It will be seen that, in fact, it was 0·030. The difference in the permanent sets of the two girders is due partly to the plates being of iron and steel respectively, but chiefly to the rivet holes having been punched in the one case and machine-drilled in the other.

TEST OF SPRING GIRDER (STEEL) FOR BUCCLEUCH DOCK BRIDGE, 1878.

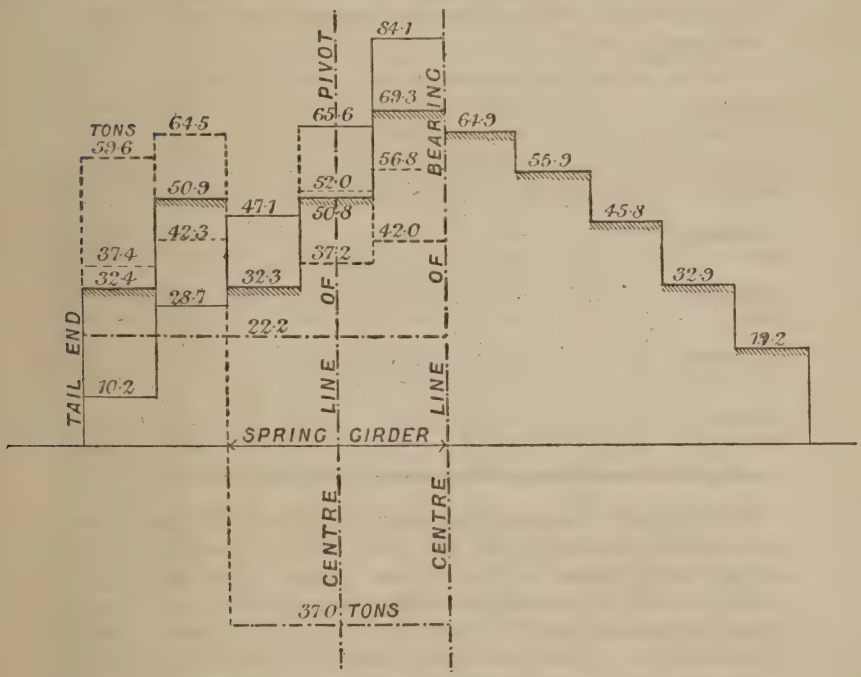
Tons Pressure on Guage = say, net.	32 30	42 39	52 48·5	62 58	70 65
Deflection	1·03	1·31	1·58	1·86	2·06
Set	0·00 0·034	0·06 0·032	0·08 0·031	0·08 0·031	0·08 0·030
Deflection	—	—	—	—	2·06
Set	—	—	—	—	0·07 0·030
Deflection	—	—	—	—	2·06
Set	—	—	—	—	0·06 0·031
Deflection	—	—	—	—	2·01
Set	—	—	—	—	0·03 0·030
Deflection	—	—	—	—	1·98
Set	—	—	—	—	0·00 0·030
Deflection	—	—	—	—	1·98
Set	—	—	—	—	0·00 0·030

In these tests it was not necessary to exhaust the set in each case before proceeding to the next higher pressure, as was approximately done for the Poplar bridge. The four girders varied slightly in testing, as might be expected, but the effect of the differences would be entirely inappreciable in the working of the bridge. These tests being carried beyond the maximum working load gave a true permanent set to the spring girders, so that in the six years since the erection of the bridge it has not once been necessary to use the adjusting apparatus, showing how well the spring girders have maintained their elasticity. The actual clearance at the bearings is now about $\frac{1}{8}$ inch (which is found quite sufficient), so that there would appear to be $\frac{1}{8}$ inch set during the six years, if the full clearance of $\frac{1}{4}$ inch was originally given.

As the author has before remarked, the design of the main girders would not require notice, were it not for the changes of stress caused by the reactions of the spring girders. The total reaction of each pair, when the bearings of the bridge touch, being 124 tons, equally divided to each end, there is an

upward pressure of 62 tons at the bearing. This alters none of the internal stresses of the main girders, but simply relieves the bearing plates of so much load, transferring it to the pivot. There is also a similar upward pressure of 62 tons at the third vertical from the bearing, which has to be balanced at the tail-keys by an increase to the lifting pull on the anchorage. Owing to the unsymmetrical transverse section this pressure of 62 tons is unequally distributed to the three main girders,

Fig. 4.



A receiving 23·8 tons, B 28·0 tons, and C 10·2 tons, the additional lift at the tail end caused thereby being 13·9 tons at A, 16·4 tons at B, and 6·0 tons at C. The result of this additional lift is an increase of the stresses in the diagonals of the girders for the two bays next the tail-end, and a diminution in the remaining three to the bearing, the total sum of the stresses in the diagonals being exactly the same as it would have been without the spring girders.

The stresses in the diagonals of main girder A (as an example of the others) are shown and analysed in the above diagram (Fig. 4), wherein the fine lines represent graphically the

stresses arising from loads considered independently of those from the spring girders, and the strong lines the actual stresses due to their combination.

The full lines represent the stresses when the live load is all over; the plain dotted lines, those when the live load is on the outer half only, i.e. from the bearing to the meeting face; and the lines dotted thus .—.—.—., the stresses due to the action of the spring girders treated separately. Of the latter, that above the base line of the diagram is the stress due to the additional lift at the keys, that below the line the stress due to the direct upward pressure at the end of the spring girder. The shaded edging indicates the maximum stresses throughout. All these are tensional stresses. When the load is on the inner half—i.e. from the tail end to the bearing—compressive stresses occur in the diagonals of the end and third bays, being 9·5 and 1·8 tons respectively in girder A and 2·0 and 5·0 tons in girder B. The maximum equivalent stress per square inch being only 0·63 tons, no special provision is needed.

The effects of the spring girders on the top and bottom booms of the main girders are of comparatively less consequence, as will be seen by the following table of those in the bottom boom of girder A.

Number of bay from tail end	1	2	3	4	5
Stress without spring girder	28·7	61·1	97·2	137·0	180·5
Actual stress including spring girder	45·7	95·1	119·8	148·3	180·5
Difference due to spring girder	17·0	34·0	22·6	11·3	0

It will be observed that, although the difference is throughout one of increase, yet the maximum stress at bearing is finally the same, and, further, that the minimum section of the boom representing, at 4 tons to the inch, a resistance to compression of 70 tons, there is no practical increase of section in the first bay, and in the second only an increase of 25 tons stress to be provided for instead of the theoretical 34 tons. Still the fact remains that about 5 per cent. additional metal has to be put into the booms of the main girders to provide for the stresses produced by the spring girders; while in the diagonals no additional metal is required, it is only differently disposed.

There are no other points in the construction of the bridge that require special notice, but the author may be allowed to record

the verification of his calculations of friction. Before the hydraulic gear was attached the actual power required to swing each leaf of the bridge was tested by a dynamometer. The southern leaf was started with 560 lb. pull, and kept in motion with from 448 to 1080 lb. The other leaf required rather greater power. But when it is remembered that all was quite new, and none of the parts worn to their work, it is evident that the true gauge of the friction was the minimum force given above. The calculated friction, as before stated, was 645 lb. The bridge now works with perfect ease, the ordinary time of opening being two and a-half minutes. The calculated deflection at the meeting face under a full load of tank engines from end to end, and with the carriage and footways loaded to 1 cwt. per super foot, was 1·2 inch for the centre girder B. The system of calculation adopted by the author allowed for the varying stresses per square inch of section in the successive bays of the girder, thereby considerably modifying the results that would have been obtained by assuming (as is usually done) a uniform stress throughout. The test load actually employed was less than half the full load, but on carefully reducing the results to the same conditions as formed the basis of the calculation, the equivalent mean deflection was found to be 1·05 inch.

The bridge was completed in November 1879, and is used for the general traffic of the railway. It was constructed by Messrs. Westray, Copeland & Co., of Barrow-in-Furness, who also supplied the hydraulic machinery.

The total cost, exclusive of masonry, was £4422.

	£
Of this, the cost of the bridge proper was	3010
The spring girders and their adjustments (including cost of testing), with the pivots and other parts constituting the provision for movement	950
Hydraulic machinery	462
	£4422

The hydraulic machinery for a traversing bridge would have cost about 2300*l*. The system of spring girders, therefore, compares very favourably with that of lifting and traversing as to cost, besides its great advantages in readiness and rapidity of action—vital points where a railway opening bridge is concerned.

Ulverston Canal Bridge.

The bridge over the Ulverston Canal is of an entirely different class from that just described, and the conditions of

economical construction vary essentially. The clear span of waterway is in this case small, being only 27 feet, and the peculiar arrangement and construction of the bridge are due to the sharp skew—48°—at which the railway crosses the canal. The depth of the foundation, viz. 34 feet below rail level, made it still more important to obtain the lightest form of construction. The towing path and public road on the north bank of the canal rendered it necessary that the motive power should be established on the other side of the canal only. A double swing bridge, as used at the Buccleuch Dock, was therefore unsuitable. A single swing bridge (1) would have been about 112 feet long, owing to the skew, and its weight about 140 tons. A traversing bridge (2) working in the direction of the railway, was approximately estimated. Its length would have been the same as for the swing bridge, the moving weight less, but the machinery more expensive. A traversing bridge (3) similar to the last, but divided longitudinally, so as to work each line of railway separately, was then considered. This has been successfully done at Carmarthen, and at Newport, Isle of Wight, over the river Medina, and, though subject to some disadvantages, would have suited a skew construction, as the length required for each division of the bridge would have been reduced to 92 feet, and the weight to 38½ tons, or 77 tons moving weight in all, as against 110 for design No. 2.

The author then suggested to Mr. Stileman (4) that by making the bridge traverse in a direction at right angles to the canal, instead of in the line of the railway, the minimum of span and therefore the minimum of weight would be obtained, and with it the minimum of traverse. Mr. Stileman approved of the suggestion, and allowed the design to be worked out. The result justified the anticipations, for the weight to be moved was reduced to 54½ tons, which had only to be traversed through 28 feet.

In the following table are compared the results of the four systems, as to dimensions, weights, length of traverse, and work to be done in opening and closing.

No.	Dimensions.		Weight.	Length of Traverse.	Work in Opening and Closing.
	Length.	Width.	Tons.		
1	112′	27′	140	To be swung through 48°	
2	112′	27′	110	52′	5720 foot tons
3	92′	twice 13′	77	42′ 6″	3273 „
4	61′ 6″	60′	54½	28′	1526 „

The cost of No. 2 was not estimated, for it was clearly out of competition. The approximate estimates for the other three were as follows:—

No.	Fixed Work.	Moving Works.	Machinery.	Totals.
	£	£	£	£
1	300	2000	800	3100
3	300	1250	1500	3050
4	400	850	760	2010

The actual cost in the last case was 1850*l.*, as will be given in detail. The above amounts do not include motive power or foundations, but it was obvious that in both these items the proposed arrangement must have a decided advantage, and that it would be more than 1000*l.* less costly than either of the other forms. The skew traverser, therefore, being adopted, upon grounds which would apply to any bridge of similar or sharper angle, the next important question was the character of the foundations. The borings showed that no hard stratum could be reached at less than 34 feet below rail level. It was decided to employ cast-iron screw piles, both as most economical and as affording the greatest facilities for erection without interfering with the waterway of the canal. The arrangement of the bridge also lent itself well to the use of screw piles, its extended lines of face distributing the load more widely than would have been the case with a swing bridge. Cast-iron piles of three different sizes were used to meet the varying loads. The letters indicating these refer to the plan on diagram 5.

No. of Piles.	Marked.	For Loads.	Diameter.	
			Of Screw.	Of Pile.
18	Q	up to 12 tons	2′ 9″	12″
12	P	12 to 32 tons	4′ 6″	19″
9	O	32 to 52 tons	5′ 9″	24″
39 in all				

The greatest load estimated for any one pile was 51 tons, including its own weight and its proportion of the dead and live load. The central row of piles on the southern side of the waterway is connected at top by a cast-iron capsill, on which are the bearings for the opening part of the bridge, and which carries also eight small hydraulic rams for lifting the bridge

ready for traversing. The forward end of the bridge rests on the row of piles on the opposite side of the waterway, and the rear end on rollers fixed upon a third row of piles 30 feet 10½ inches back from the central row. Other piles carry the fixed girders, which take the place of abutments, and reach the canal bank on each side.

The general construction of the Bridge is shown on Plate III.

The moving part of the bridge consists of eight main girders 2 feet 6 inches deep, and one light face girder supporting the overhanging flooring. These are connected at each end and at the centre by bracing frames, and are diagonally intersected by rail bearers. The latter have plate-webs throughout, as have the main girders for the bays which carry the live load, and for those over the central and rear bearings. The rest of the bays in the main girders have open webs, as shown on Plate IV. The mode of making the skew connections between the rail bearers and the main girders is also shown in detail on Fig. 5.

The flooring is 2-inch creosoted fir, resting on fillets or packing pieces on the top of the main girders and rail bearers. For reasons of local convenience the whole moving framework is planked over, adding eight tons to the weight, but this is not necessary to the structure, and should not be taken into account in comparing weights with other forms of bridge. The rails are steel, of bridge section, and are bolted through the timberwork to the tops of the rail bearers. A similar rail is riveted under and forms part of the bottom member of each main girder.

Owing to the diagonal crossing of the rail bearers only two of the main girders are alike, either in stress or counterbalance. This latter is provided by means of cast-iron slabs on each side of, and bolted through, the web at the rear end of the girders, except in the case of girder B, in which the counterbalance has to be fixed at the forward end. The distance of the rear rollers is so fixed that the centre of gravity of the moving structure is always between them and the central rollers. When, therefore, the bridge has to be opened, the central rollers are lifted by means of the small hydraulics before referred to, and, raising the bridge off its bearings, both at the forward end and at the centre, hold it supported entirely on the central and rear rollers, ready to be run back into the brick pit built to receive it (Plate III.) As the deflection at the forward end is about 1½ inch, a lift of 1 inch at the roller is sufficient to free the bridge. The small hydraulic rams vary in diameter from 5 inches to 6 inches, according to the respective weights assignable to the girders under which they act. The lifting gear is shown on Plate V.

The traversing power is obtained from two pairs of hydraulic rams with multiplying sheaves, placed as shown on the plan (Plate III.) in the brick pit above referred to.

The actual cost of the work was :—

		£
Foundations, including 144½ tons cast iron and 1½ ton wrought iron		1426
Brickwork, masonry and excavation		464
		1890
Fixed work in abutments—	£	
23¾ tons wrought iron	411	
Timber	47	
		458
Opening bridge—		
39¼ tons wrought ironwork and steel rails	670	
6½ tons counterbalance	55	
Timber	150	
		875
Hydraulic machinery—		
For lifting	329	
For traversing	187	
		516
		3739
Engine house	400	
Engine and boiler	330	
Tank and accumulator	264	
		994
Watching, &c.		40
		4773
Dolphins		425
		£5198

The whole of the bridge and machinery was executed by Messrs. Westray, Copeland & Co. of Barrow-in-Furness.

DISCUSSION.

The PRESIDENT said he was sure that all present would agree with him that they were much indebted for the paper which had been read. It would be a valuable contribution to the transactions of the Society, and many of the Members would read it with perhaps even more interest than they had heard it.

Mr. A. T. WALMISLEY said that those who had to deal with docks knew that the success of a dock in the present day depended in a great measure upon its being adapted for railway purposes, in which case there was railway and road traffic over the bridges to be considered as well as water-traffic under them. Both of these claimed attention ; and the result was that where a bridge crossed a dock, provision had to be made for the bridge to open. During a recent holiday in the Lake district (knowing that this paper was to be read), he made

it his business to spend a day in going to look at the bridges which had been described that evening, and he obtained the permission of Mr. Frank C. Stileman, the Engineer to the Furness Railway Company (the owners of the Barrow Docks) to have the bridges worked and to spend as much time as he liked upon them. His son Mr. F. Stileman, the Resident Engineer, very courteously placed a locomotive at his (Mr. Walmisley's) disposal, so that he had an opportunity of seeing the bridges under a variety of circumstances. He was particularly pleased at the ease and rapidity with which they were opened and closed. The Buccleuch bridge was opened several times a day, but the traffic along the Ulverston canal did not require the bridge over it to be so frequently opened. He stood underneath both these bridges while they were being moved, and he also crossed them on a locomotive both at low and high speed. The mechanism was really perfect. Standing underneath the Buccleuch Dock Bridge and observing the action of the spring girder, he saw the great merit of that element being introduced into the construction in the ease with which it accommodated itself to the influence of a variable load. The bridge balanced itself splendidly, and he ascertained that no adjustment of the spring girder had been found necessary since the first erection. The locomotive had no difficulty at all in getting on to the lines of rail when crossing the bridge. The key arrangement caused the bridge to be as continuous as a fixed bridge, although it could be opened with the greatest freedom. He had not seen the bridge at Poplar, but he had no doubt it worked equally well. The admirable disposition of the material in the Ulverston bridge, there being plate-web under the passing load, and lattice-web in the overhanging parts, showed how carefully the detail of the design had been considered. He was very pleased to make these remarks as the result of his recent visit, and to say that the description which Mr. Light had given of the working was fully justified. The bridges would be admired by any one who, when paying a visit to the locality, would observe their construction.

Mr. J. H. Cunningham said that, if he understood Mr. Light aright, three other forms of construction had been taken into consideration, viz., a traversing bridge, a lifting bridge, and a bridge of one span or leaf, and reasons which appeared satisfactory had been given for adopting the bridge of two leaves. But admitting that that was the most suitable form, it seemed to him that a comparison should rather have been made between a two-leaved bridge lifted by hydraulic presses under the pivots, and the same kind of bridge lifted by spring girders. He was inclined to think that the former

would in some respects have been the better arrangement. At any rate it was not apparent that the spring girder was preferable to a hydraulic ram, and he should be glad to know why the former device was adopted.

Mr. J. B. Redman said that the very lucid and practical paper which had been read was of singular interest in three aspects. One was the great necessity which existed for enlarged entrances to our docks, in consequence of the use of very large steam vessels in the mercantile marine. A second was the agitation which had arisen for inter-communication between the two banks of a navigable river, as illustrated by the Thames; and the third was that this return to the main elements of the early mode of inter-communication between two quays of a navigable entrance, was a singular endorsement of the instinctive genius of our early engineers. The first bridges of the Metropolitan and Provincial Docks were, in their main elements, the type of the Buccleuch bridge. He could well remember the original wooden bridges which spanned the various locks and entrances of the East and West India Docks. They were in outline much what the Buccleuch bridge was. Æsthetically they were elegant in form, and they were admirable in working, and performed every desired function. They were replaced, when worn out, by cast-iron swing-bridges, and these again by wrought-iron. He would ask the author to tell them in his reply what were the main reasons which induced a return to the old form of bridge. That information would be of interest, because there were some three or four different types of movable bridges. A special interest attached to the lifting, or Bascule principle, from the fact that the Corporation of London had obtained powers to erect such a bridge across the Thames at the Tower of London, designed by Mr. Horace Jones, the City architect. Gentlemen who were familiar with that bridge would know that, as first designed, the leaves opened only up to a certain angle, so that the 200 feet of navigable space was very considerably reduced for the tall-masted vessels.

Professor Robinson said he felt, as he heard the paper read, that the matter had been so skilfully thought out by those who had designed and executed the work, that it would be out of place to criticise it without having more time than he had had to digest the facts. Mr. Redman, in the remarks which he had made, omitted altogether reference to the special feature of the Buccleuch Dock Bridge which had been explained in the paper, viz., the spring girder. To discuss that appeared to him to be the author's object in bringing forward the paper. He (Professor Robinson) confessed that there was something about the spring girder which was very fascinating, in view of the figures which had been given by the author, to show that so much saving had

been effected in the weights of the parts and in the method of working. If it had not been for the great success which had attended the working of the spring girder bridge, as they had heard from the author and from Mr. Walmisley, one would have thought that there was a little complication about the arrangement. He certainly confessed that he had never had to design a bridge with a spring girder, such as Mr. Light had described; and in the absence of data he should not venture to say that the spring girder was not the right form for these particular cases. Mr. Cunningham referred to the practice of applying hydraulic pressure under the pivot, and he (Professor Robinson) had designed several bridges on that principle, both for drawing-back and for swinging. In reference to the diagrams, it could not be insisted upon too much, that those who wrote papers should illustrate them properly, as it was one of the most important things they could do. Very few authors took the trouble to bring forward a paper in a form which enabled the meeting to grasp the salient points quickly. In the present case the audience had been able to follow the whole subject from beginning to end, with an amount of clearness which he had never seen excelled in that room. Mr. Light had set a good example to authors of papers.

Mr. W. Parsey did not think that there was any difficulty in arriving at the conclusion that the spring girder was a clever and ingenious principle. The question which he wished particularly to raise was with regard to the adoption of a one-leaf or a two-leaf opening bridge. There was no doubt that, as regarded material, the two-leafed system would be the most economical, because there was a smaller overhang to deal with. But it appeared to him that there would be a loss of time in opening and closing the bridge. In a one-leaf arrangement the turning would be effected in one operation, and it would only have the segment at the opposite side to close against. But when there were two leaves the one half must be turned clear of the other before that could begin to move and the time occupied by this clearing movement must be so far a loss.

Mr. Bernays asked whether any experiments had been made with reference to the effect which changes of temperature would have on the bridge. The space between the girder and bearing when unloaded was so very slight, that he should say that the extremes of temperature in this and in other countries might possibly affect it to some extent. He presumed that the paper had really been brought forward to introduce the spring girder, rather than for the purpose of describing the particular form of bridge. So far as he knew, the spring girder was a novel expedient, and it seemed to be a somewhat bold one in a structure of that kind, in which rigidity, rather

than elasticity, had been generally aimed at. The sliding-bridge also seemed to him novel. He must confess that he should have liked to see a little less of the girder work about it. There was a great deal of overhang at one corner. The girders A, B, C, and D seemed, too, very much longer than the real main support of the bridge would require; and this would suggest the question whether less material might not have been used.

Mr. Homfray said that the author had stated that the quarter of an inch which was allowed for the clearing of the bearings was reduced to one-eighth, and that seemed to be a very small space to allow for the deflection due to the extension of the top boom from a rise of temperature, even within the limits experienced in this country. But of course they were inclined to magnify the clearance required, because, with the ordinary type of bridges that pass under the hands of most engineers, it was the deflection at the nose end that affected them most. The author appeared to have gone very carefully into the various methods of crossing the passage, with the view of getting the lightest bridge in the cheapest form. One gentleman had told them that the use of a double leaf for a lock entrance was not novel. It was in fact, much used at the present day. Mr. Lyster used it at Liverpool, and it had been proposed for the Thames. Speaking of the Thames, he might correct a statement which had been made with regard to the bridge that was proposed over that river. He believed that the actual opening would be 200 feet, as sanctioned by the legislature, and the two leaves would lift into a vertical position, and give an absolute clearance of 200 feet, the only connection between the towers being a light wrought-iron foot bridge over the top, which would be, he believed, 130 feet above water level, so that up to that height there would be an absolutely clear space 200 feet wide. As to the speed at which Mr. Light's bridge was opened, he did not think that was at all special. They were accustomed to fast speeds now-a-days. He had known the big bridge over the Tyne opened and closed again in three minutes, reckoning from the time that the traffic was stopped for opening, until it was allowed to cross again. It had been done in two minutes and a-half. He must congratulate the Society, if the diagrams that evening indicated the usual style in which diagrams were prepared for their papers.

Mr. R. Gordon said he considered that the spring girder was especially suitable for places where there were no hydraulic arrangements, and it would be exceptionally valuable where the bridge had to be turned by hand. Perhaps he might ask Mr. Light whether he had seen the method used by Mr. Sellers, in his cast-iron turn-table, for relieving the friction on the top of

the pivot, which is about 15 inches in diameter, with two steel plates on top. He had a number of conical rollers, about 3 inches diameter and 3 inches in length. They took off a great deal of the friction. These turn-tables were from 50 to 60 feet in diameter, and were very heavy.

The CHAIRMAN, in closing the discussion said, that he thought that the paper had been a very interesting one. In their profession they were always coming across things which they had never heard of before. He knew very little of the subject himself, except what he had seen, chiefly in Holland. In that country, the bridges were drawn up, part on each side, and the passengers had to wait about ten minutes or a quarter of an hour, before they could get across. The people were in no hurry in that country. In England, people were a little more chary about their time. He did not doubt that the means which Mr. Light had described in his paper were well calculated for facility of opening and shutting. Still, he had certainly seen in Holland some very ingenious contrivances.

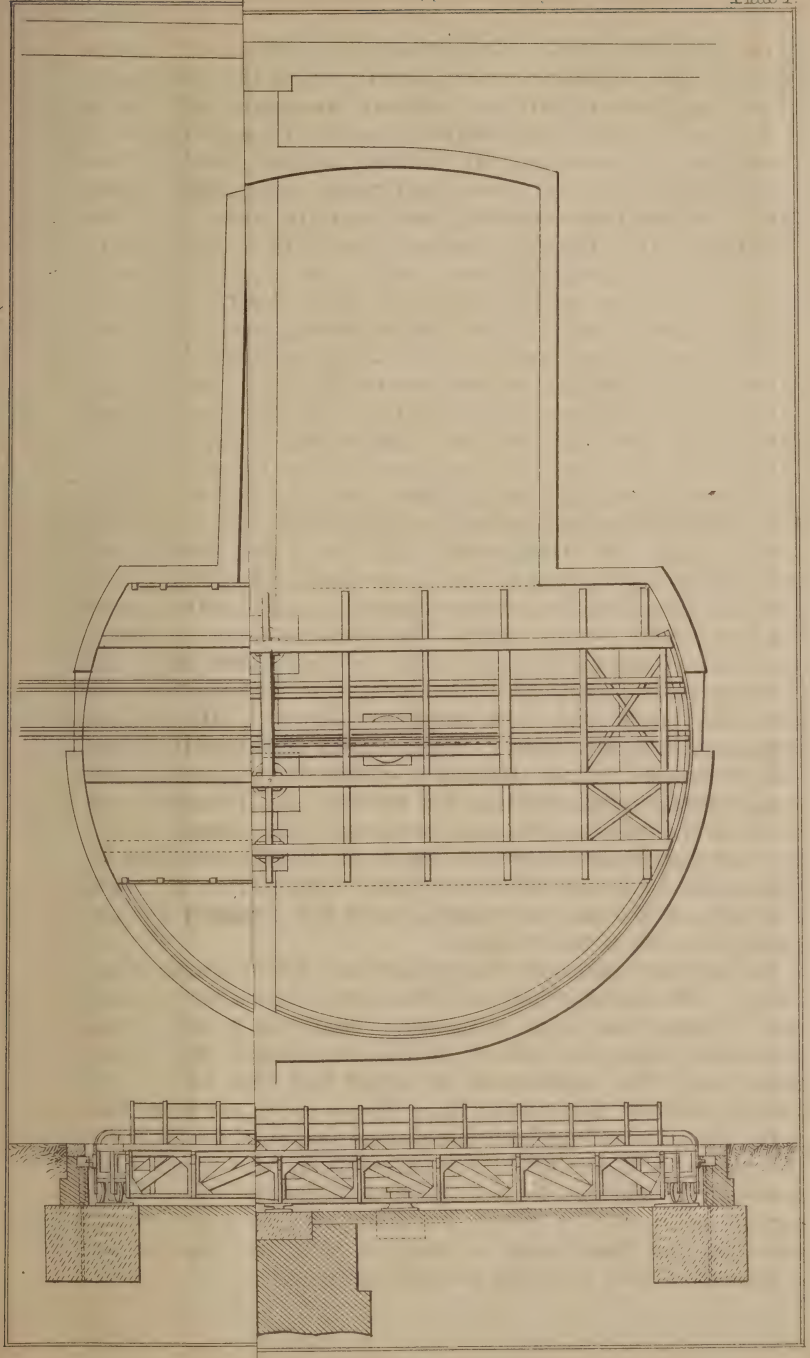
Mr. C. J. LIGHT, in reply, said that he had been glad to hear Mr. Walmisley's entire confirmation of the guarded statements he had made in the paper as to the working of the bridge. As might be gathered from Mr. Walmisley's remarks, the pressure upon the pivot was almost constant. It must be remembered that when the passing load came over, all that it did was to deflect the spring girders, and from the moment that the bearings touched, the rest of the load, however great, had no effect at all upon the pivot. The surplus weight all went direct into the bearings. Therefore he considered that the pivot was under most favourable conditions for maintaining a uniform and proper wear, as, in fact, the result proved. The only hitch that ever occurred with the bridge itself was in lubricating the pivot. At an early period there was some difficulty in keeping the oil on the pivot, and he believed that this arose solely from a little carelessness in cleaning, or something of that sort. At all events the bridge was jacked up, the pivot was carefully cleaned and re-oiled, and since then there had never been the slightest difficulty with it. The adjustment of the spring girders had never been touched. A somewhat unexpected use for these adjustments came out in the construction of the bridge. When the work was put together it was found to be rather difficult to keep it in a plane, as might be imagined from its light construction, though it was amply strong for its load. It was then that the importance was found of having four points on which to adjust it—and the ready means of doing so—at the ends of the spring girders. Mr. Cunningham wished for a comparison of the system adopted with that of a lift by means of an hydraulic press at the pivot. Of course, if they replaced the

spring girders by an hydraulic lift at the pivot, they might have a dead bearing exactly as in his bridge, but they would be under the disadvantage that a bridge so constructed would not be always ready for turning, as this one was. Time would be required for the operation of lifting, while in the spring girder construction the bridge was always resting freely on the pivot when there was no live load upon it, and therefore it was ready for turning at any moment. The hydraulic turning-power being equal, it appeared certain that the time required for opening the bridge must be less with the spring girder arrangement, than with the hydraulic lifting pivot. He held that that was a point of very considerable importance, and a sufficient answer to the question. Besides, hydraulic lifting would increase the consumption of water from the high pressure mains and draw so much more upon the available water-power of the docks, while the spring girder made no such demand. He had purposely given the cost of the spring girder separately in the paper, to afford the means of comparison with the cost of an hydraulic lift at the pivot. He thought that no one would say that the spring girder was not originally cheaper, and certainly quicker in action, and did not use far less water. Mr. Redman had made some very interesting remarks as to former bridges. It was perfectly true that the bridge described in the paper was a return in general form to the original one; but he did not read the paper for the purpose of describing the double-leaved bridges. He read it solely on account of the spring girders. The reason for preferring a double-leaf construction was the confined character of the site. There was not a long quay wall, but narrow quay-heads forming a passage between the two docks, and if the bridge had been a single-leaf it must have overhung one of the docks to a considerable extent and interfered with the berthing of vessels. Incidentally also, the double-leaf admirably suited the spring girder arrangement. These remarks would also answer Mr. Parsey's question. He had often thought, looking at the elevation of the bridge, "Is not that bridge too light?" though he well knew that it was not so. The appearance of extreme lightness was very greatly due to the fact of the main girders being raised above the roadway, which reduced their apparent depth, while still allowing a full proportion. Mr. Robinson noticed that the system appeared to effect a considerable saving in weight. He (Mr. Light) must again draw attention to the fact that this saving in weight also means saving in the consumption of high-pressure water in the hydraulics, for turning, besides the whole of that for lifting. Mr. Bernays raised an important point as to the effect of temperature, and Mr. Homfray had spoken on the same subject. It appeared to him (the author), however, that the possible effect

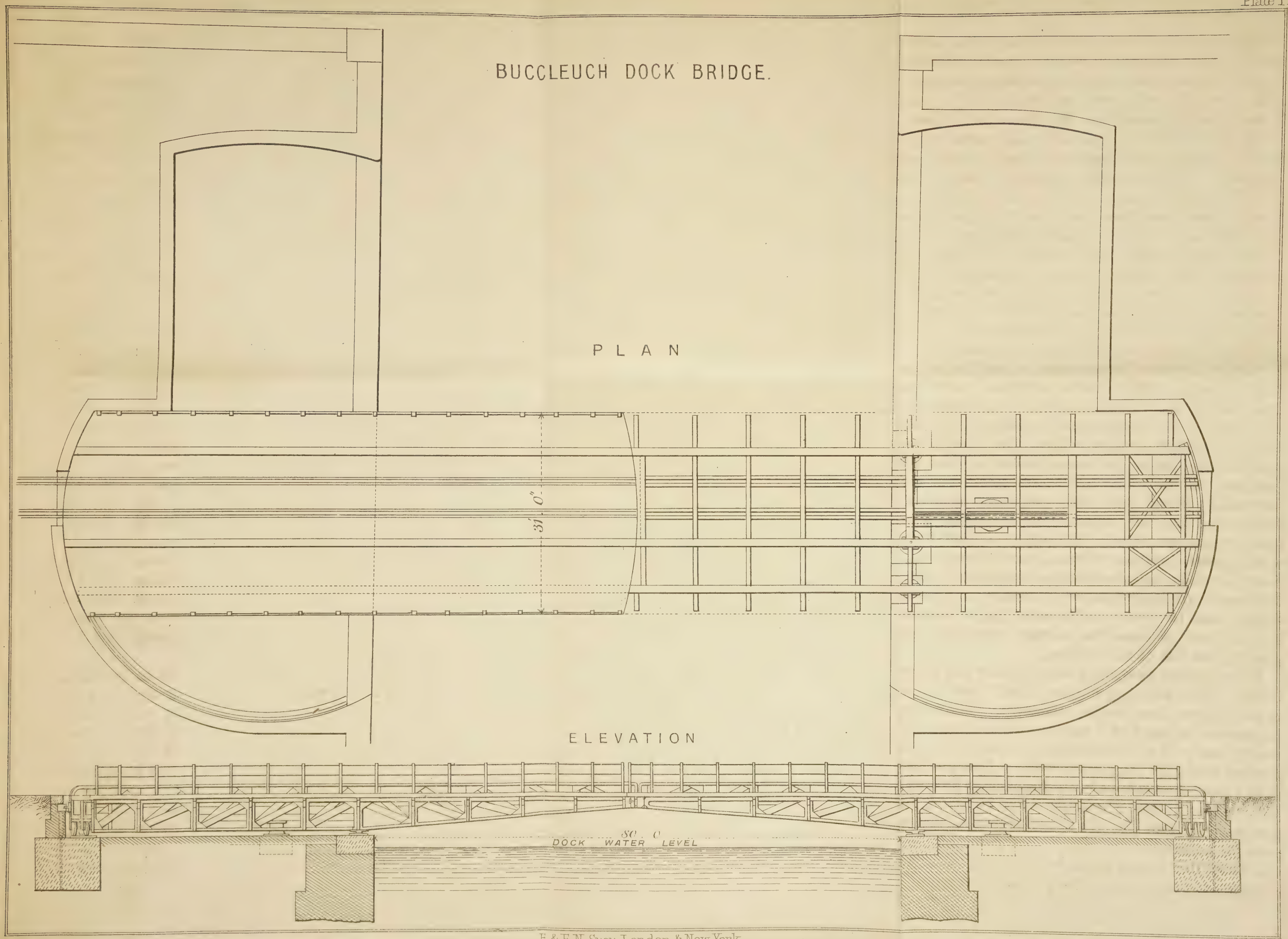
on the clearance at the bearings had been somewhat misapprehended. The expansion would directly affect the clearance at the meeting-face and tail ends, where it was amply provided for in the keys, but only very indirectly and to a minute extent the clearance at the bearings. Mr. Bernays had said that the spring girder struck him as a bold and novel experiment, because rigidity, rather than elasticity, was generally aimed at in such structures. The elasticity, however, was only used for keeping the bridge itself ready to swing on the pivot. As soon as the moving load came on, the elasticity gave place to a rigidity equal to that of any ordinary bridge resting upon abutments, because the moving load brought it down upon the bearing plates and the bearing became absolutely rigid. As an illustration of the low friction at which the bridge worked, he might remark that lately the chains of the moving apparatus having to be detached for repairs, the bridge was moved by manual labour applied at the tail-ends, when it was found that four men started it easily and when it was once in motion two men could easily keep it going. Mr. Gordon said that one of the circumstances under which this system might be especially valuable was when there was no hydraulic power available. A proof of that remark was the Poplar bridge, which, for fourteen years at least, as stated in the paper, had been moved by hand-power only. Mr. Homfrey had informed him that during the last five or six years hydraulic power had been employed instead. He was not acquainted with Mr. Sellers's improvement of which Mr. Gordon had given some details. He had no doubt that the arrangement would greatly reduce friction, but the very small bearing areas must, he thought, involve rapid wearing of the plates. One of the most important things in a bridge of that class he had described, was to give a sufficiently large diameter to the pivot. This did not increase the friction, but it did certainly lengthen greatly the life of the bridge.

He regretted that only one speaker had referred to the Canal bridge. Mr. Bernays had said that there seemed to him to be more girders than were necessary. That was a very natural impression upon first looking at the plan, but if Mr. Bernays would study the construction he would find that none of the girders could be dispensed with. Every effort had been made in the design to reduce both dimensions and weight, and, in fact, the girder A had originally been omitted, but it was found necessary to add it. No doubt elaborate diagrams were an important addition to a paper, but from his own experience he could say that there must be plenty of time and assistance at command, if they are to be properly prepared.

Plate I.

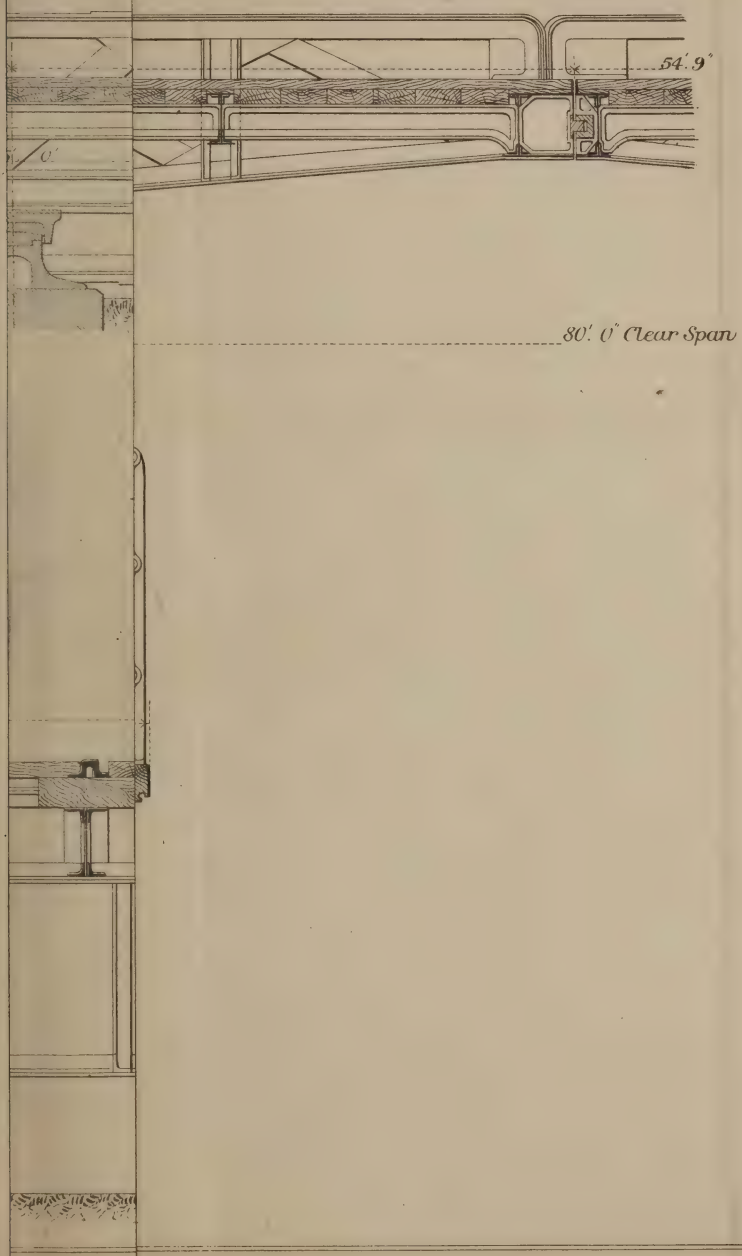


BUCCLEUCH DOCK BRIDGE.



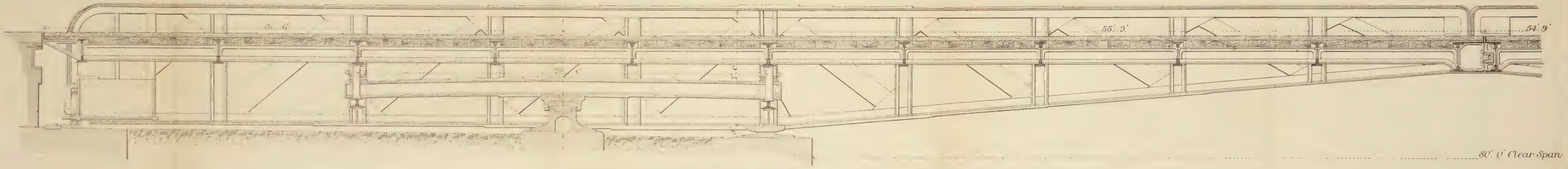
E & F. N. Spon, London & New York.

Plate II.



BUCCLEUCH DOCK BRIDGE.

LONGITUDINAL SECTION.



Scale 3/16" = 1 foot.

TRANSVERSE SECTION AT PIVOT.

Scale 3/8" = 1 foot.

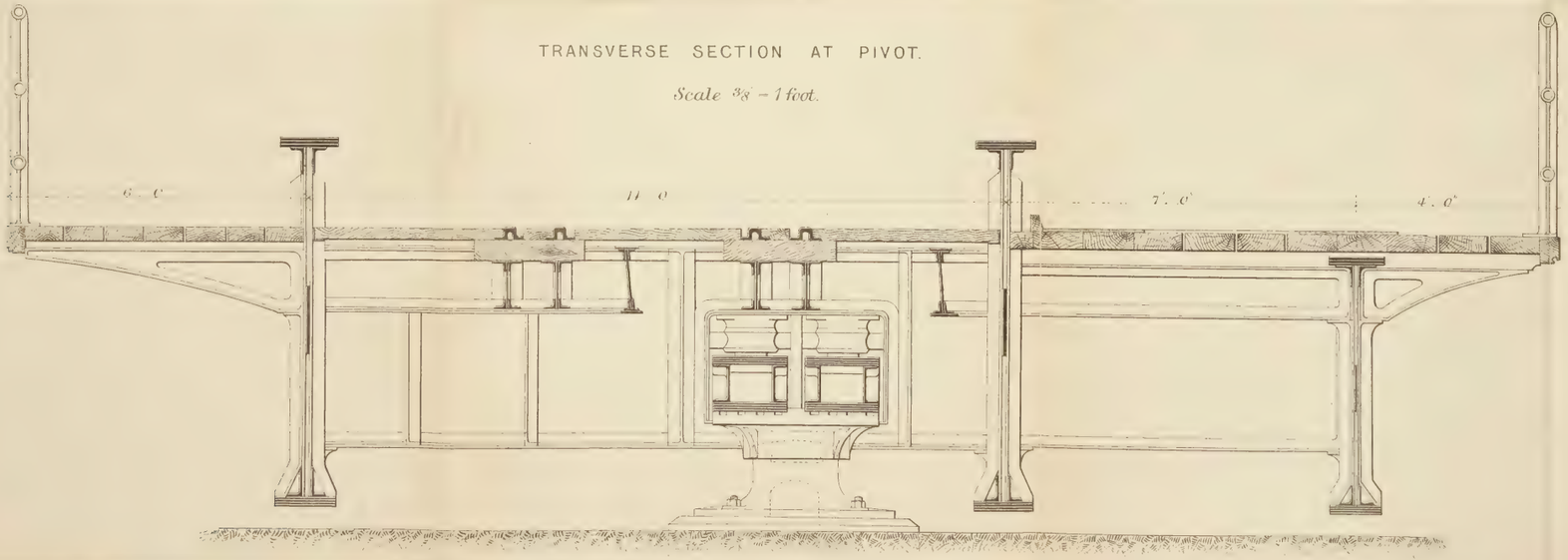


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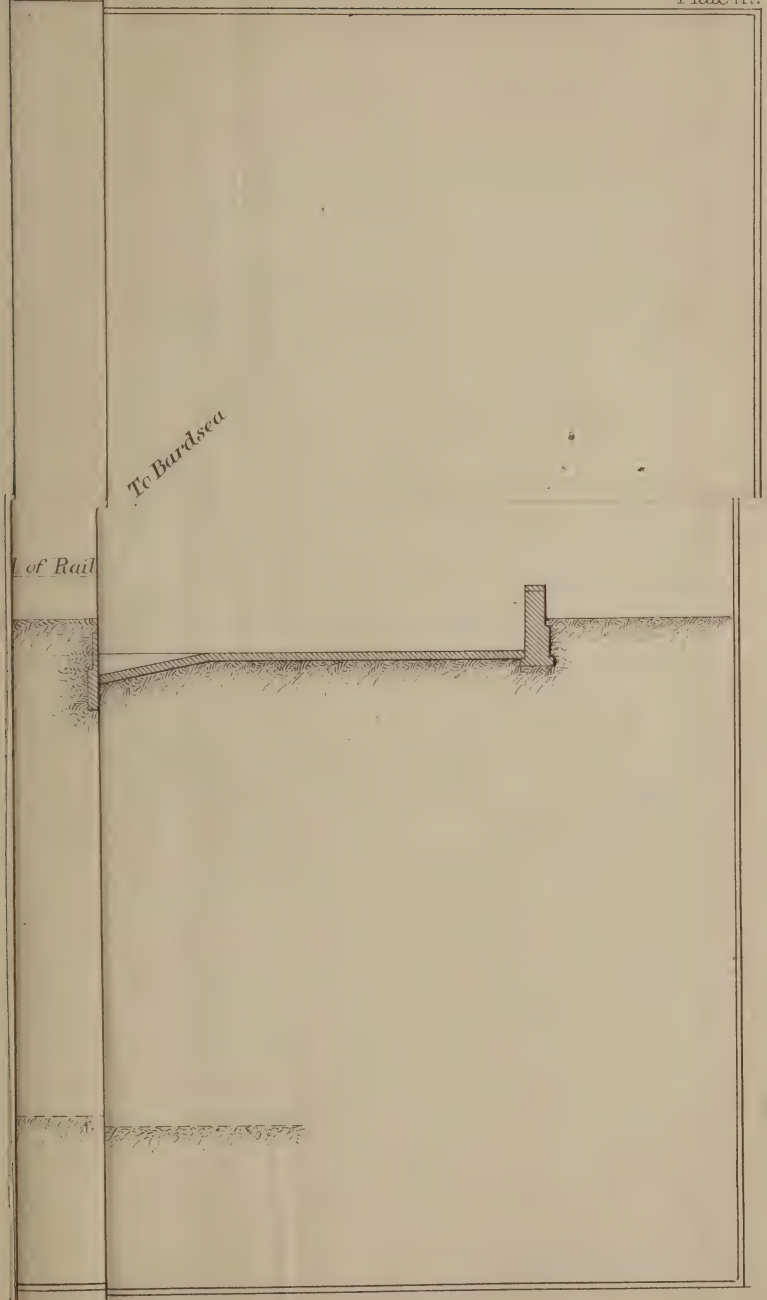
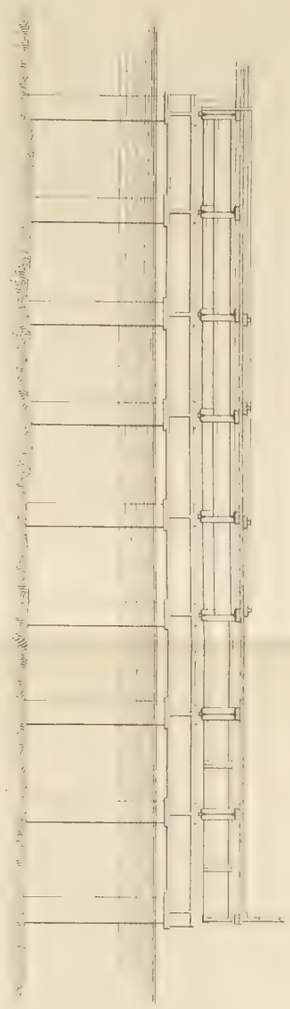
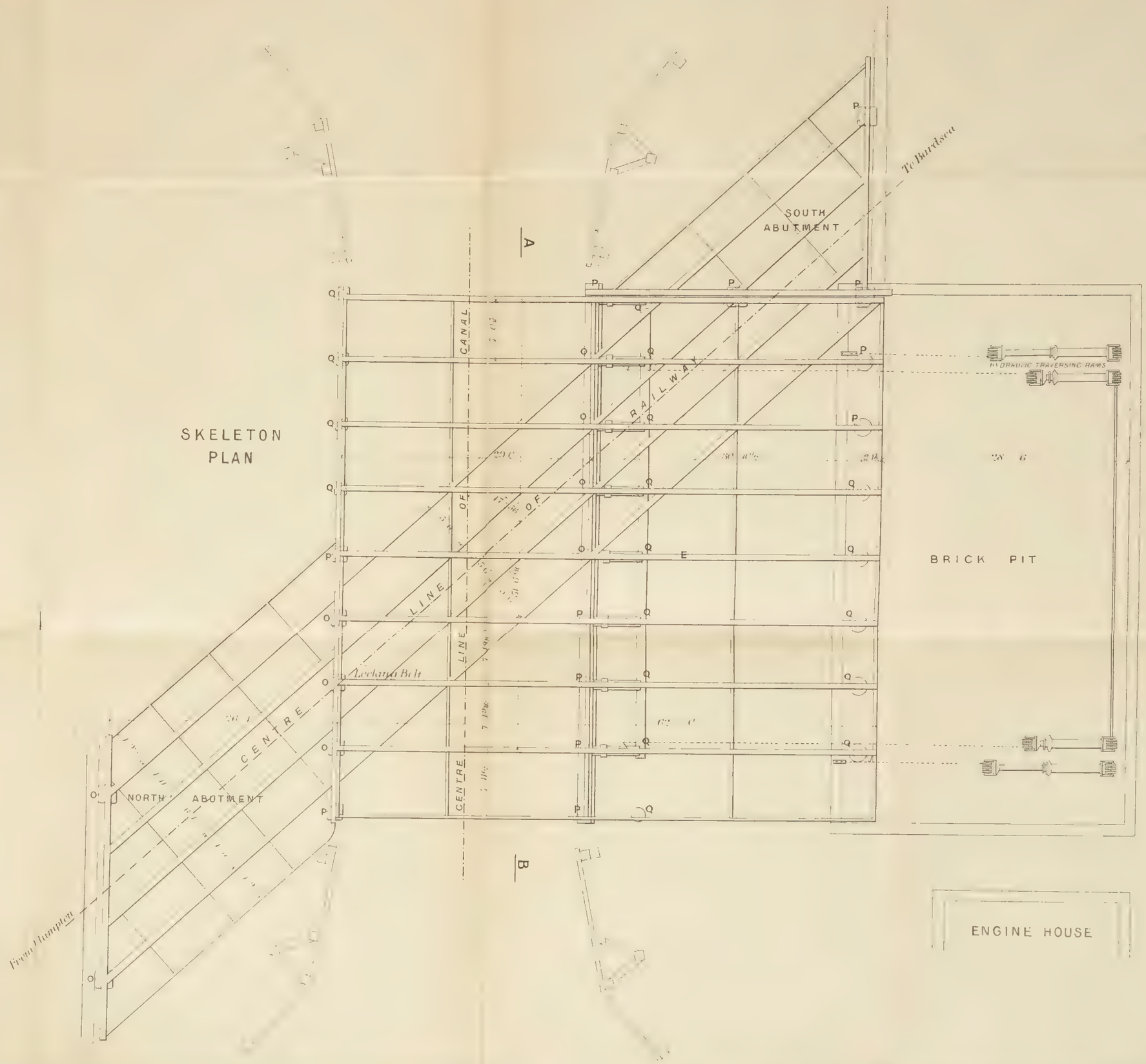
Plate III.



ULVERSTON CANAL BRIDGE.





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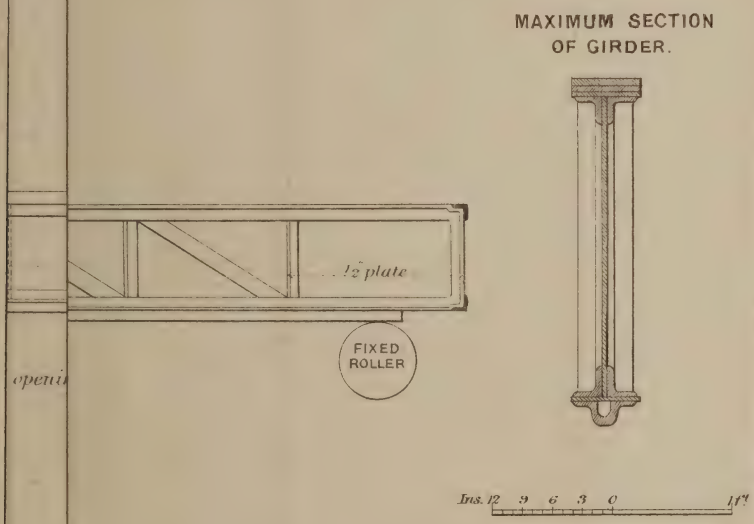
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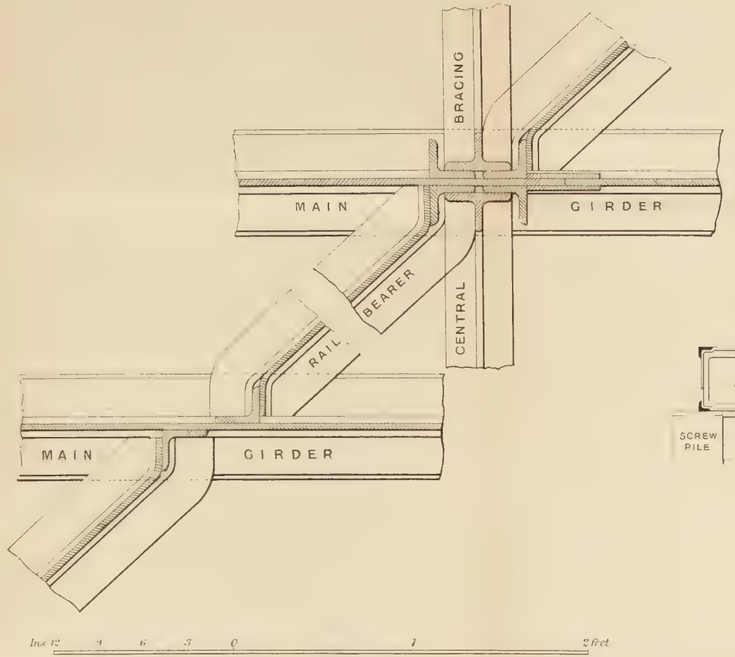
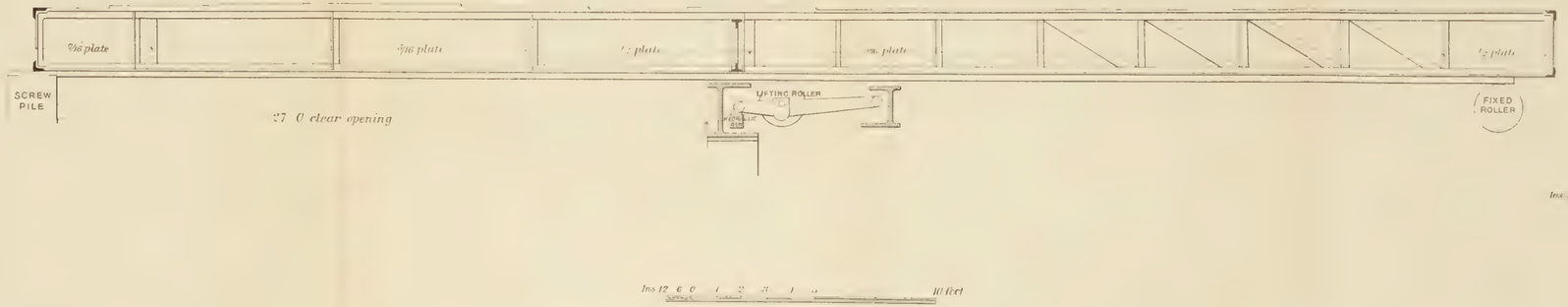
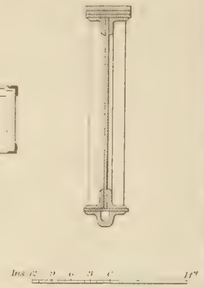


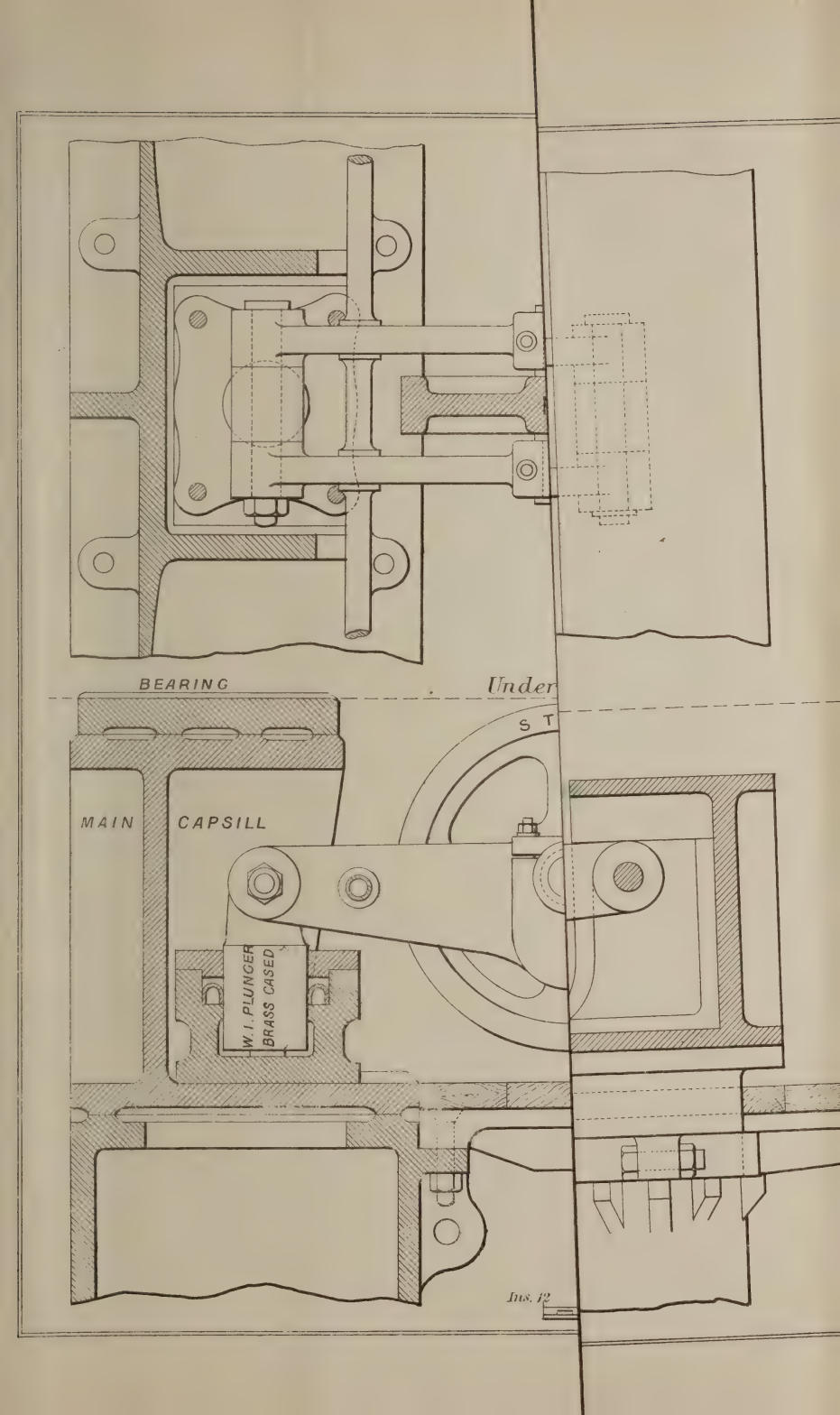
ELEVATION OF MAIN GIRDER. E.



MAXIMUM SECTION OF GIRDER.



J. & F. N. Spon London & New York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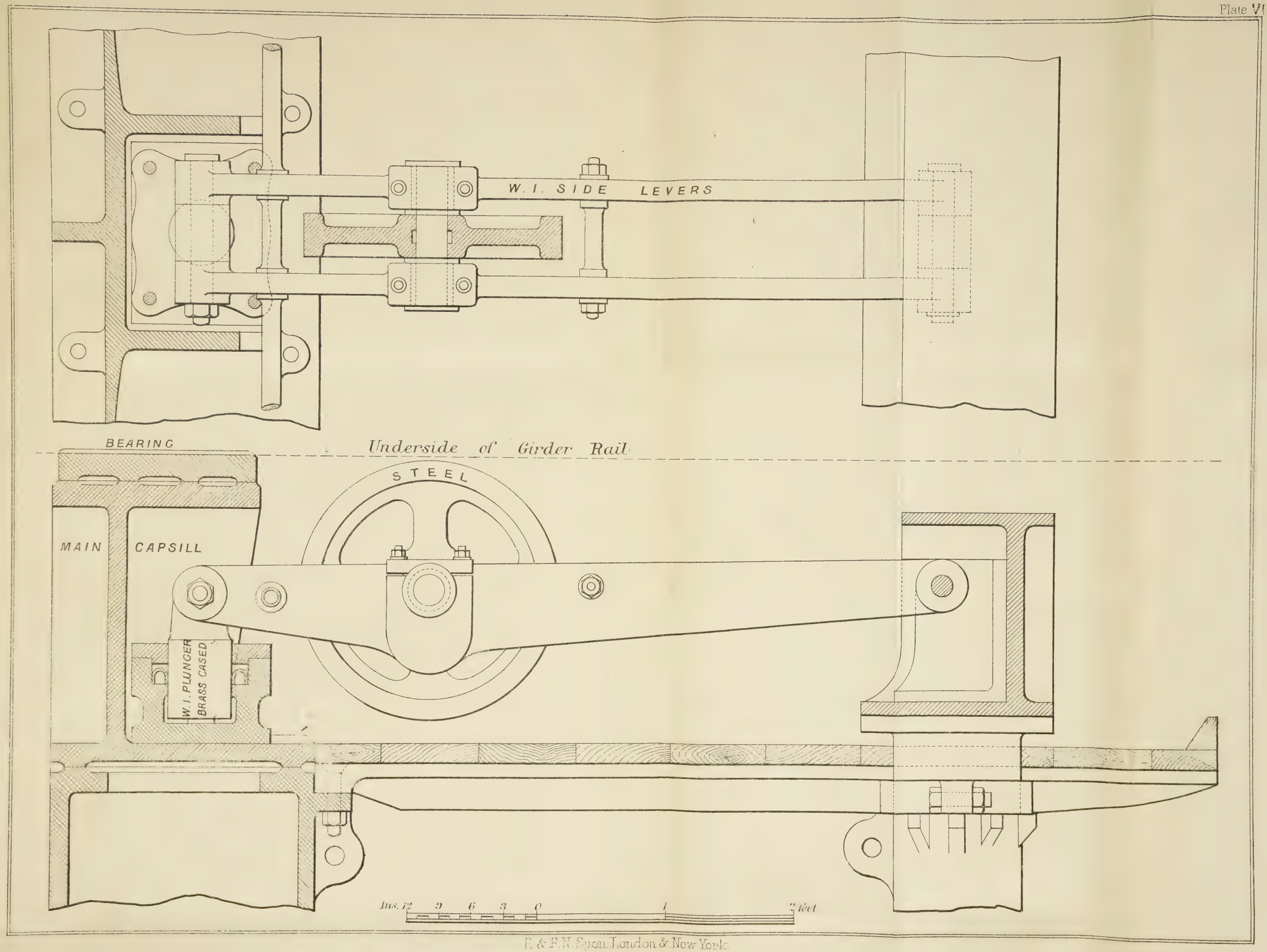


E. & F. N. Spon, London & New York.

November 2nd, 1885.

CHARLES GANDON, PRESIDENT, IN THE CHAIR.

TIDAL APPROACHES AND DEEP-WATER ENTRANCES.

By J. B. REDMAN, F.G.S., F.R.G.S., M.INST.C.E.

THE naval supremacy, hitherto unchallenged, and the pre-eminence attained by this country in commerce, are both largely resultant on its insular position, and on the great range of tide around these islands, permeating as it does numerous estuaries, tidal rivers, and deep reaching lochs, bays, and coves. This necessitates at the same time special arrangements for retaining afloat heavily-laden vessels on the reflux of the tide, and hitherto these have been mainly confined to affording the necessary depth at high water, so that in effect all our great naval basins (with few and recent exceptions) and all our commercial depôts may be styled tidal. But owing to the rapid and recent transition of the major part of foreign imports and the attendant passenger accommodation into large steamships of 3000 to 5000 tons, requiring correspondingly greater depth of water, arrangements of a non-tidal character are now wanted. The necessity for rapid transit, due to the almost universal use of steam as the motive-power both on the voyages out and home, and in dock for loading and delivering cargoes, acts in the same direction. In other words, we now require at low water a greater depth than what we were satisfied with a few years back, for the old East Indiaman, at the highest range of the tide. Hence we are compelled to consider how far existing works may be altered to meet this modern demand, and what are the characteristic features to be recognised as necessary for new harbours and docks, so as to give marine access independent of variations of tide. Dependence upon the tide as our great commercial carrier renders its movements of special interest to an insular commercial community like ours, and a glance at the tidal map of the British Isles, will show how highly favoured they are for the pursuits of commerce or for naval warfare.

The first fact to be borne in mind is that twenty hours

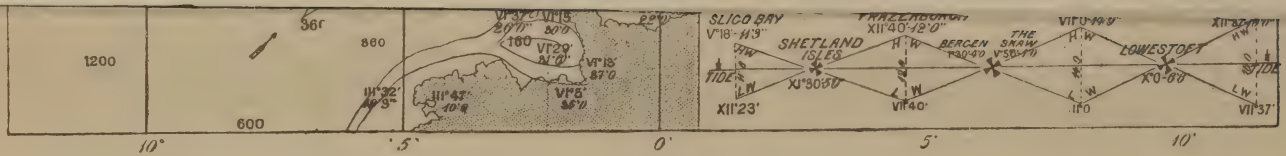
elapse before the great Atlantic tidal wave has made the complete circuit of our isles, and that thus the Genesis of the English Channel flood tide is two tides earlier than that of the one which passes down the North Sea and meets it near the Thames estuary. These three semi-diurnal pulsations of the tide, of constant and reversed recurrence, entail a comparatively stationary condition midway in each wave, termed the "node," "hinge," or "axis" of the tide, on which each of these pulsations appears to rotate; and at those neutral points, though the tidal currents have the same velocity as elsewhere, the range of the tide becomes wonderfully less, as shown upon the diagram accompanying the tidal chart. It will be seen from this lapse of time for the completion of the tidal circuit that when it is high water off the coast of Ireland it is low water in Morecambe Bay and at Liverpool, and *vice versâ*; and that, although the period of the tide is the same on the eastern English coast as on the Atlantic Galway coast, it is, in effect, two tides later. For example, when it is high water at 4h. 15m. on the south-west coast of Ireland, it is at 4h. 30m. at Flamborough Head, but the following day's tide.

The high water at the Scilly Isles at 4h. 30m. makes high water in the Thames at 11h. 45m., and at Liverpool at 11h. 23m.; the same tide passing round the north and south of Ireland about the same time—viz. 5 o'clock—meets in Dublin Bay and in Morecambe Bay by 11 o'clock. The same wave, working north and turning south in the same period between the Orkney and Shetland Islands, arrives off Fraserburgh at noon. In the next five hours a second wave has arrived by 4h. 30m. off Flamborough Head, and this is supplemented by a third wave of seven hours to the Thames. The "nodes" of these three constantly recurring and reversing waves are, of the first, at Portland, for the English Channel; at Fair Head and Arklow, for St. George's Channel, north and south of Ireland respectively; and in the Pentland Frith, for the north of Scotland; of the second wave, off the Scandinavian coast; and of the third wave, in the North Sea.

On the Tidal Diagram*, the varying range of tide is shown by the breadth of the band indicating the general littoral path of the tide and by the numerals, the confluence of the tidal waves by double stars, and the nodes by single stars.

This hasty sketch of the movements and variations of the tide around our islands shows how favourably they are situated by natural position, and all the great centres of commerce, such as London, Liverpool, Cardiff, Newcastle, Hull, &c., are

* Originally published to illustrate Chatham Lectures, 1877, and subsequently by "Engineering."


1200
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SLIGO BAY
SHETLAND ISLES
BERGEN
THE SKAW
LOWESTOFT
TIDE
10°
5°
0°
5°
10°

LANDS END
SCILLY ISLES
LIVERPOOL
MARGATE
PORTLAND
SKERRIES
WEXFORD
TIDE
SLIGO BAY
SHETLAND ISLES
FRAZERBURGH
BERGEN
THE SKAW
CROMER
LOWESTOFT
SHEERNESS

To face p. 144.

situate on large tidal estuaries and rivers, which from their configuration induce an accelerated range of tide, rendering such sites of exceptional value as commercial depôts.

Non-tidal sites.—To meet the modern demand for constant deep-water basins and docks, somewhat exaggerated descriptions have been put forth of certain sites as non-tidal. In illustration, it is only necessary to refer to the extension works at Portsmouth Dockyard, where the largest ironclad can now be docked and undocked at any time of tide, and brought out into the harbour where there is seven fathoms at low water; but the channel seaward, a mile in length, does not carry more than half that depth, so that a vessel of great draught must, after all, wait for the tide to get to or from the anchorages at Spithead or the Solent. So, again, with Port Victoria, on the Medway, used by the South-Eastern Railway, or Queenborough, on the opposite (right) bank, the Continental station for the London, Chatham and Dover line, a depth at low water of from 30 to 40 feet may be commanded; but to get to or leave this deep-water reach, the shallows south of the Nore must be crossed, and they carry only half the depth of water. So also at Tilbury, there will be depth of water in Gravesend Reach for the largest vessel, as every one knows; but to get into it, the Alexandra Channel, the Yantlet Flats, the shoals in Sea Reach, the Lower Hope, and the lower part of Gravesend Reach, all with little more than 20 feet at low water, have to be passed. A ship of great draught must, therefore, wait for the tide, if arriving about the period of low water. This applies to a great many of our deep-water tidal estuaries. The Blackwater, in Essex, for example, has attracted attention from its magnificent expanse of tidal water, and deep-water projects have been talked of for it, the shoals that encumber its mouth at low water being lost sight of. On the other hand, such sites as Cardiff and Barry, in the Bristol Channel, or Milford Haven, are unassailable in their deep-water character.

The two chief ports of the empire, London and Liverpool, cannot, however, be termed non-tidal, as neither can be entered by the largest vessels at any period of the tides. London, however, possesses an advantage over Liverpool in this respect, for she has rather more than double the depth at low water over her natural outer sills that Liverpool has over her outer sill or bar. The approach to London is also greatly improved for heavily-laden vessels of large tonnage by the buoying and opening up of the Bullock (or, as re-christened, the Duke of Edinburgh) Channel, five miles eastward of the Alexandra Channel, with double the depth of water commanded by the

latter at low water, save a few patches at the entrance recently buoyed with 19 to 22 feet at low water. This channel involves a short détour of three miles, but leaves no impediment whatever at any period of the tide until a vessel arrives off Sheerness. A very large question is involved in considering the availability of the port of London to vessels of the *City of Rome* type, and that is the condition of, and what is taking place in the low water navigable channels intersecting the shifting sands of the Thames estuary.

There are two main outer southern deep-water channels leading upwards to the Nore, after rounding the North Foreland, called the Queen's and Prince's, the latter and outer channel having superseded the former. From it branches the Alexandra into the Deeps, which again carry deep water up to the Nore. Between Leigh and Yantlet Creek there have been great changes. The various channels have deepened eastward and shoaled westward, and the shoals have tailed upwards in the same direction. The material is of a light, silty, flocculent character, and dredging here might not be productive of self-maintaining channels, but frequent repetition of the process might be required. It is clear that the tidal action will only maintain certain low water sectional areas north and south of the Leigh Middle Shoal, and the general tendency has been to abrade the north shore, so that the Leigh Channel, the circuitous bend north of the Leigh Middle, has deepened, and the Fairway Channel, abreast of Yantlet Creek, has correspondingly shoaled. In the centre of this oscillating area of submarine sand, a shoaling to the extent of 20 feet has taken place, and at the western entrance of the Leigh Channel a similar loss has occurred, but to the westward, above this entrance, south of the Leigh Little Middle Shoal, there is a parallel increase of depth. On a centre meridian from Leigh Church to the City Stone at Yantlet Creek, over an area of about 2 miles square, the average of identical soundings in the low water channel shows no change, the means of all such soundings as can be localised as the same amount to 26 feet.

The remarkable changes in the Leigh Middle Shoal may readily be seen by comparing the charts by Mackenzie, 1824, by Norie 1830, by Bullock, 1833, 1840 and 1856, and these charts corrected in 1873 and 1879, and lastly in 1882. In fact, so great are these changes, of alternate deepening and shallowing, balancing each other over certain defined areas, that the Hydrographical Department of the Admiralty has rested content of late years to test alone the navigable character of the two channels north and south of this shoal. It may

however, be mentioned that evidence brought forward by the promoters of the Tilbury Docks project (the East and West India Dock Company) went to prove that there was a greater minimum depth in some of the reaches than shown in the last issue of the Admiralty charts of the Thames, but the fact that a clause was inserted in their bill to empower them to dredge in the Thames, shows clearly how close a shave they were aware that it was. The last Admiralty chart of Sea Reach shows some local variations, but in the main the navigable channel at low water has only 22 feet. A chart, by Commander Tizard, R.N., of 1883, shows in Lower Hope Reach, below Cliffe Creek, patches of 23, 24, and 25 feet, and here the East and West India Dock Company have been actively engaged in dredging ballast from off the crests. This chart also shows minimum depths of 22 and 23 feet off Yantlet Flats. In Leigh Channel, however, the minimum is 25 feet, but this course is narrow, tortuous, and unused by large vessels.

As regards minimum depths in these estuary channels, the only reliable data for comparison are the charts issued under Government authority by the Hydrographical Department of the Admiralty, and the value of any comparison must depend upon the observer making use of the Admiralty datum, viz., the level of low water referred to fixed points at Sheerness. This can only be done by accurate levelling from the Ordnance B.M. nearest to the site of comparison. It may, however, be observed that marine surveyors, as a rule, understate rather than overestimate navigable depths, to avoid any chance of misleading the navigator.

Thames Reaches.

The kind of navigation afforded by the Thames Reaches is distinctly shown in the fine series of Admiralty charts by Bullock and his successors, and even at the present time there is little to be desired below the Gallions. A review of the leading widths and depths at low water shows clearly the carrying capacity of the river for ocean steamers of the *Orient* and *City of Rome* type, drawing 26 to 27 feet when fully loaded. The upper part, at Woolwich, carrying more than 20 feet, averages 200 yards in width; below Dagenham it widens out to double that width, whilst below Purfleet it is 1000 yards wide, with 20 to 30 feet water, and Long Reach, from Purfleet to Greenhithe, with 30 feet water, is from 400 to 600 yards in width. Fiddler's Reach, below Greenhithe, with 30 to 40 feet, is 800 yards, whilst at Broadness, the sudden turn, with 50 feet

of water, is only 200 yards wide. Northfleet Hope, with 35 to 50 feet, is from 500 to 600 yards broad, and Gravesend Reach, with 35 to 60 feet, has the magnificent breadth of from 600 to 800 yards, and forms the well-known anchorage, where vessels engaged in the foreign trade formerly lay for several days, as a rule, and many even now do for several tides. At such portions of this low water channel as between Gallions and Dagenham, and at Broadness, where the widths are only equal to the length of such ships as the *City of Rome*, very careful steering must be necessary, with little room for such a vessel to turn suddenly in her course; but this only applies to about 3 miles out of the 15 from Gallions to Gravesend.

Large steam ships up to 5000 tons have become so numerous, that it is clear that all those which draw much in excess of 20 feet will avail themselves of the docks nearest to the sea, as in addition to the difficulty of rounding such a point as Broadness, there is the chance of a fleet of such vessels being detained in the upper reaches for several tides by fogs, necessitating their all coming down together when the fog suddenly lifts, or *vice versâ*, ascending the river together if the detention occurs in the lower reaches. This accumulation occurred, to quote an illustration, on January 22, 1882, the day before a new moon, with an abnormal condition of the atmosphere (the barometer nearly 31 inches), a fog settled down on the country generally. It lifted somewhat the next day at Gravesend, and nearly a score of large steamships ran down soon after the 1 P.M. high water, including two Peninsular and Oriental vessels. Both these latter passed down without stopping at Gravesend, having taken their passengers on board in the Albert Dock, thus showing that with increased depth Woolwich might be made almost as eligible as Gravesend for the point of departure.

Docking Vessels.

To dock a vessel like the *City of Rome*, with a length over all of 600 feet, at all hours, across a tideway with a velocity of 3 to 4 miles per hour, involves very special arrangements of entrance, with covering piers or jetties and outlying dolphins and warping moorings. The experience derived from docking one of these leviathans, with all these aids and two tugs on her weather side, will illustrate this. At the new (Blackwall) entrance to the East India Docks, with 30 feet 6 inches of water on the sill and the single pair of gates very close to the river, it was found almost impossible to dock a vessel even at high water with comparatively no current, when the wind blew up the river from the eastward, and a supplementary open timber

dolphin pier, triangular in plan, was constructed above the entrance. This was almost knocked to pieces, and had to be considerably strengthened. The difficulty of entering a non-tidal deep water basin, at or near high or low water, will be great. Will it be ever attempted at half-flood or ebb?

Port of London—Divided Jurisdiction.

It has occurred to many that the time is arriving for the legislature to review the whole question of the management of the Port of London and conservancy of the river, including the direction of the docks, and that all might be advantageously placed under a joint port trust, as at Liverpool. At a meeting of merchants and wharfingers it was stated that goods landed at Liverpool were delivered in London within a day, whilst five days were frequently expended after their arrival in a metropolitan dock before they were landed at the wharf, and that these delays were driving much of the trade to the outports. This difficulty, as regards goods, will in all probability be enhanced if a large proportion of foreign imports are to be landed at Tilbury or Gravesend, or even below those sites.

Amalgamation.

The tendency of dock companies towards amalgation arises in a measure from the fact that there is now virtually a monopoly on the south side of the Thames, and in all probability a similar result will be developed on the north bank by the two colossal companies, the London, St. Katharine's and Victoria, and the East and West India, effecting a union and swallowing up the Millwall, thus shutting out for years to come all competition from rival companies. Whether this is a state of things to be desired by the commercial community is for them to judge. In effect it came out before the committee of the House of Commons on the Tilbury project that an agreement had been entered into between the two great companies, as regards rates, virtually securing a monopoly and accounting for the London Dock Company not appearing as opponents, as they had done against the Dagenham project in the previous session.

Metropolitan Docks.

So many papers have been published on the docks of London that it is unnecessary to do more than take a glance at the subject. It was only towards the close of the last century, in

1795, that the legislature first turned its attention to what was then a grievance, viz., the crowded state of the Pool, as now the narrowness at certain places and want of depth, with the absence of efficient lighting in the upper reaches, is a pressing question of the day. The contest was keen among rival designers, as shown by the report of 1799, and has been well epitomised by Mr. Farrow, of the East and West India Dock Company, in his well known treatise on the Docks of London. Captain Perry's Dock, at Blackwall, and the Greenland Dock, Rotherhithe, now one of the Commercial Docks, were of ancient date, and the Merchants' or London Docks were the first modern instalment, to be followed by the East and West India, St. Katharine's, and Commercial Docks, and in more recent times by the Victoria, Millwall, and Surrey Docks, the last an enlargement of the old Surrey Canal and Basin. They all had independent directorates, but have now merged into three great Metropolitan Dock Companies, the St. Katharine's and London, including the Royal Victoria and Albert Docks Company, the East and West India Docks Company, and the Surrey and Commercial Docks Company, added to which is the modern Millwall Dock Company. In speaking of the position of these works the mileage down the river is taken from London Bridge, as the head of the tidal Port of London for sea-going vessels. The same datum was adopted in describing the river reaches in the author's paper on the "River Thames," read before the Institution of Civil Engineers in 1877.

St. Katharine's Docks.

The St. Katharine's Docks, only three-quarters of a mile below London Bridge, are surrounded by costly warehouses now crammed with teas from the Albert Dock and vaults; and it is a tribute to that master engineer, Thomas Telford, that its outer entrance is only 3 feet 6 inches less in depth than that of the most modern and deepest entrance on the Thames yet in use, and that the ratio of its quayage value to the area of water enclosed is the highest in the port. The outer sill of the entrance lock is 27 feet below Trinity, but the inner sill is 4 feet higher. Engineers have been long in convincing themselves that level sills throughout an entrance lock is the best arrangement, and we have seen recently at the new Albert Dock the necessity entailed of lowering the inner sill 3 feet in order to command the desired 30 feet at high water, Trinity standard.

London Docks.

The London Docks have three main entrances (the Upper Hermitage entrance, long disused), between one and two miles down. These docks also are surrounded by massive warehouses and vaults, besides possessing the Cutler Street warehouses, formerly the property of the East India Company, which cover four acres of ground, and are largely used for storing tea, silk, carpets, and other valuable produce from India and China. The average stock warehoused is estimated at from four to five millions sterling, and that passed through annually at about double that amount. The main lower entrance to these docks has 28 feet over the sills.

West India Docks.

The West India Docks, once under a separate company, with entrances at Limehouse and Blackwall, respectively three and six miles down, have extensive ranges of warehouses for sugars and West Indian produce, and sheds for mahogany, &c. These docks were extended when the City Canal, previously purchased and converted into a lie-by and timber pond, was afterwards, formed into the new South Dock. This alteration, however, crippled materially the timber trade of this company, which had been an increasing one, and was accommodated by the City Canal and its tributary timber-ponds. The Blackwall entrance to the South Dock has 27 feet 6 inches in depth.

East India Docks.

The East India Docks, which also for years formed a separate establishment, 6½ miles down, have warehouses for teas and Indian produce. They were added to by the recent enlargement of the Blackwall Tidal Basin, and the amalgamated East and West India Docks Company possesses warehouses in the City near Billiter Square. These also, with those in Haydon Square belonging to the London and North-Western Railway, were formerly the property of the great East India Company. The new entrance to these docks commands the greatest depth of any in the port of London at present, viz. 30 feet 6 inches below Trinity.

Millwall Dock.

The Millwall Dock, with an entrance 3½ miles down, has a limited amount of warehouse area, and is an illustration of the incompleteness of a dock without attendant warehouse capacity, that the stock of this company was comparatively stagnant until the erection of warehouses, when the money value of its share capital immediately bounded up. This dock commands the satisfactory depth of 28 feet 2 inches, and is the port of departure for a large number of big steamships. Its entrance lock is 450 feet long by 80 feet wide. A large sum has recently been expended in powerful pumping machinery to feed the dock from the river, and keep up a constant level of 28 feet on the sills, the loss of depth entailed by constant lockage through one large entrance being so great.

Surrey Commercial Docks.

On the south side of the river the now combined Surrey and Commercial Docks, with entrances 1¾ and 3½ miles down, are chiefly devoted to the timber and grain trades. The early granaries were, like the timber sheds, mainly of timber, but of late years piles of brick warehouses or granaries have been erected. The lower entrance lock, 220 feet by 48 feet, commands 27 feet, and the upper one, 250 feet by 50 feet, has 27 feet 3 inches, and the Greenland Dock lock just above the lower entrance, 209 feet by 42 feet 6 inches, has 20 feet on the sills.

Victoria and Albert Docks.

The Victoria Dock, formed by a separate company and purchased by the London and St. Katharine's Docks Company, has now two entrances, respectively seven miles (at Blackwall) and eleven miles (at Gallion's Reach) down the river, by the extension works contemplated in the Acts and recently carried out under the title of the Albert Dock. So far it marks a new era in metropolitan dock enterprise, as it commands the most seaward entrance in the river, and its evident success has induced the revival of the old Dagenham project and the construction of the Tilbury Docks.

Lapsed Acts.

A history of the different Acts obtained for metropolitan docks, but never acted on, and the reasons for throwing out certain bills for such works, would be curious. Acts were

obtained for Collier Docks at Rotherhithe, but the Collier Dock question, once a burning one, has now ceased to exist, due to the fact that the importation of sea-borne coal for the last thirty years has remained stationary or slightly declined, the yearly increase coming up by rail, and having now reached the marvellous quantity of 6,000,000 tons per annum. The old sailing collier is also becoming extinct (with its companion, the coal-whipper), and is superseded by large iron steamers, with machinery on board for loading and unloading; lighters are also being towed up by steam in fleets to the wharves and the Regent's Canal Basin. The passage of such vessels as the *Vauxhall* and *Westminster*, 1000 tons burthen, with self-contained machinery and lowering spars and funnel, plying for this commerce between the Tyne and the Vauxhall Gasworks, above the yet unaltered and reputedly impeding Vauxhall Bridge, is a startling practical testimony to the revolution in the sea-borne coal trade.

Wellington Docks.

Of recent years, the first project for docks on the south side of the river was in 1854, for the Wellington Docks at Rotherhithe. It was thrown out by a committee of the House of Commons, on the ground that the proposed entrance, in a comparatively narrow portion of the river, would interfere with the entrances to the London Docks on the opposite bank, also that the Victoria Dock (then recently constructed) had not had sufficient time for development for its effect to be seen on the constant increase in tonnage. Would not the same arguments apply to some of the projects of a more recent period?

East Greenwich Docks.

Lower down, at East Greenwich, Mr. Coles Child, once a South-Eastern Railway director, and well known on the Coal Exchange, obtained an Act for the construction of docks between Greenwich and Bugsby's Reaches, above and below Blackwall, but for which he could not enlist sympathy, or he took his commodity to a better market. It remains to be seen whether the resuscitation of the scheme a quarter of a century later, under South-Eastern Railway influence, and the Act obtained thereby, will meet with any more encouragement.

Dagenham Docks.

An act was also obtained about the same time for dockising the low-water lake at Dagenham, with a maximum depth of

over 30 feet, left after Captain Perry's successful stoppage (towards the end of last century) of the celebrated breach in the river walls. The works were commenced after a fashion, but the whole project collapsed. Will the recent Act in this case, again, be more successful? The site is too low down for an up-town dock, even the Albert Dock lightering its teas up to St. Katharine's; and it is too high up for a deep-water dock to be available at any time of tide. On the other hand, it certainly possesses one advantage, viz., the great increase in width of the low water channel from Dagenham downwards.

Tilbury Docks.

These docks are now in course of construction for the East and West India Dock Company, and are rapidly approaching completion. The great increase of large steamships, and the success of the Albert Dock, induced the East and West India Dock Company to make a strenuous effort to outflank and seek the "Ultima Thule" of the port of London down at Tilbury, 26 miles below London Bridge. The project is *primâ facie* most taking, if, as its designers assert, it could be made available from the sea upwards at all states of tide, or non-tidal, as some of its supporters have chosen to call it. The works, which the Society of Engineers visited in June last, have now been in progress about three years, and the docks will, when finished, undoubtedly draw to them all the steamships of the greatest draught, as the entrance, 200 feet wide, and the tidal basin of 19½ acres with 26 feet at low water spring tide, will form the approaches to inner docks of 53 acres area, with 38 feet at high water spring tide. Moreover, the present works can only be regarded as a first instalment, as the company has obtained land sufficient to double the capacity of this most seaward of the metropolitan docks.

Now here we may ask how many of these big ships will the company be able to afford to dock in one tide, without undue loss of water? It is manifest the margin cannot be a wide one, considering that at the Albert Dock it has been found necessary to erect four very large Boulton and Watt centrifugal pumping engines above the entrance lock, which are now very constantly at work pumping water from the river below low water through a large culvert into the dock, to keep up the water surface therein. The new Albert Dock is being worked really as a transit dock, as all valuable goods are lightered up to the London establishments.

Will this be the case at Tilbury? If so, steam lighters of large tonnage and more freeboard than existing craft will be

wanted to navigate the lower reaches, and this eventuality has, it is understood, already been entertained by the authorities.

As regards approaches to the Tilbury Docks, the Alexandra Channel, as before stated, only carries 22 feet at the minimum, and pilots say it is shoaling. It is true the Duke of Edinburgh Channel (now buoyed) has a low water depth of 30 to 40 feet, but whichever a heavy vessel uses she has 12 miles to run to the Nore, which again is 22 miles below Tilbury, so that a vessel arriving on the turn of the tide would have nearly three hours' steaming to reach Tilbury, in addition to detention for want of water, and she has in any case to pass over the thresholds of 22 feet at low water off Yantlet Creek, and those in the Lower Hope and in the lower part of Gravesend Reach. These obstructions would tell in this way: if the Nore were reached at or near low water, there would be a quarter or half-flood detention off Yantlet Creek to obtain sufficient water to proceed upwards. This, however, will be materially reduced by the dredging operations of the East and West India Dock Company, who have had a large and powerful dredger, by Hunter and English, at work raising ballast from the crests of the shoals for the Tilbury Docks works. For although there is a bed of gravel from 9 to 10 feet thick superimposed on the chalk, and all the dock, lock, and basin walls are founded thereon, it is below the level of the basin and dock bottoms; so that, unlike the Albert Dock, there is no constructive material *in sitû*.

With the above-mentioned shoals still extant the Tilbury Docks could not be called non-tidal, as has been claimed for them. Of course the Tilbury Docks will be non-tidal in the sense that the steam basins of the extension of Portsmouth Dockyard are, which are available at any hour from the circumscribed area of the tidal harbour with 7 fathoms at low water, but not from the open sea.

Dock Extensions.

The various works of extension at the upper docks have already been briefly noted; it remains now to say that they have only met for a short period the demand for greater depth, and could in no degree keep pace with the rapid increase in freightage, which is apparent enough when the fact is regarded that the foreign import and export tonnage of the port doubles itself in twenty years. This increase of tonnage is, however, no exact measure of the want of increased dock area, since the ocean steamship of to-day makes at least double the number of voyages per annum, as compared with the 1000 or 2000 tons

Indiaman. As the increased tonnage is supplied by steam vessels, a smaller proportionate length of quayage is now required to work a given traffic, and this is enhanced by the facilities now at our command for discharging and loading much more rapidly, with less cost and less loss to the merchant.

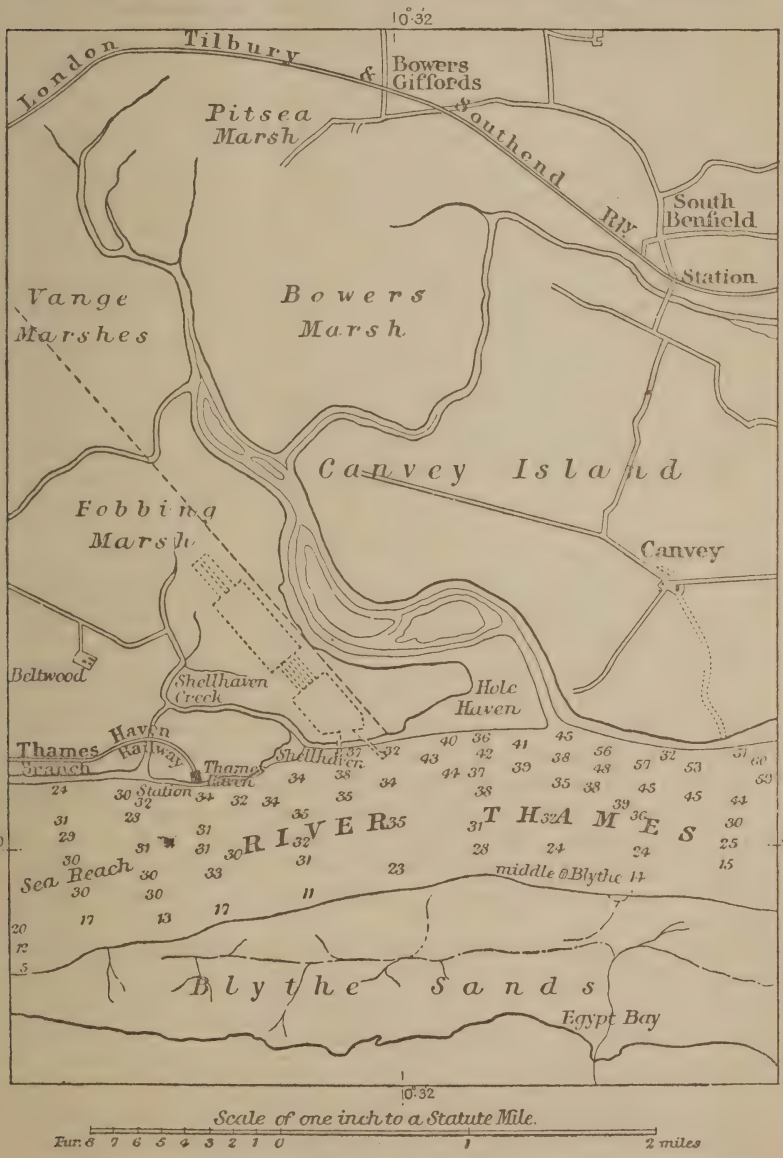
Further Requirements.

To meet the demand for accommodation for the large ocean steamer up to 5000 tons burthen, which is becoming more and more familiar to our river—the Peninsular and Oriental Company alone possessing a fleet of from fifty to sixty of such vessels, which now rendezvous at Woolwich instead of Southampton, and sail ultimately from Gravesend—it is clear that new depôts still lower down the river will be required.

Thames Haven and Shell Haven.

It is somewhat remarkable that among the lapsed docks Acts is that for Thames Haven, one of the finest sites on the river, and already possessing railway communication, situate as it is west of Canvey Island, midway between Tilbury and Southend; and that, although large quantities of cattle are landed here, no dock has yet been completed. This position, or one somewhat lower down between Shell Haven and Hole Haven, both above Canvey Island, presents greater facilities than any other on the Thames, as these sites are seaward of all the low water shoals in Sea Reach, the Lower Hope, and Gravesend Reach. They would be accessible at a quarter flood and down to three-quarters ebb by the largest steamers afloat, and would thus, with the same reservations as at Tilbury as to docking such ships on a rapid tideway, be more non-tidal in character than any other sites. One important feature of the Shell Haven site would be that the excavations would be all in clay, and only a small amount of pumping would be required. But, on the other hand, no gravel would be met with, and all required for concrete for the works would have to be brought in; but, as we have seen, this is a condition of things existent at Tilbury. The author more than two years back submitted a plan to several dock and railway authorities for a long rectangular dock, tidal-basin, and other works, with a united area of 83 acres, requiring with quays, sheds and warehouses, &c., 550 acres of land. The total estimate was somewhat over a million sterling. He was told that, while admitting the merits of the plan, and that it would inevitably be carried out by some one, there was not the remotest prospect of floating such a project at the

present time, and this opinion came from a high authority on the Stock Exchange. The site is 10 miles lower than Tilbury,



NOTE.—*Soundings are in feet below Low Water of ordinary Spring Tides, and are from Admiralty Chart No.* 1185, *by Commander Tizard,* 1883.

and no other site (save Canvey Island, the proposed sewage depôt) could be obtained lower down the river, while direct communication with the manufacturing districts would be obtained through the Great Eastern system.

Importance of the Question.

When it is considered that this subject may without exaggeration be termed national in character, no apology is needed for bringing it forward at the present time. A real revolution in the commercial marine of the country is going on; and whilst many circumstances, to the minds of naval architects, appear to point to the conclusion that the length of 500 to 600 feet—ten times the maximum breadth of 50 feet to 60 feet—with a maximum draught of 27 feet (limited by the Suez Canal, through which most of these large vessels have at times to pass) are the outside dimensions likely to be arrived at, yet the increasing number of such steamships necessitates great improvements to our national estuaries and rivers, and very great extension of the dimensions of tidal entrances, locks, &c.

Dredging Plant.

The number of vessels employed in dredging harbours, rivers, and docks, has greatly increased, the character of the machinery has equally advanced, with a corresponding reduction in the cost of raising the material, and this, at the same time, from a greatly increased depth. In the early part of the century, the ballastage of the Thames was exclusively in the hands of the Trinity Corporation; and it is less than half a century since the primitive spoon-and-bag lighters were superseded by the steam dredger, with its two chains of buckets, one on either gunwale, or single chain working through a central well. The material is dredged from quite double the depth reached in early practice and at about one-eighth the cost, including interest on the plant.

These dredgers are now made seagoing vessels, and have been navigated to our colonies.

Deep-water Entrances.

The recent struggles between the Liverpool Authorities and the promoters of the Manchester Ship Canal as to the effect of certain entrance training works proposed by the latter, show how keenly alive the shipping communities are to the importance of maintaining the integrity of our great tidal estuaries.

Liverpool has been reproached with remaining content with a low-water depth of 10 feet over her bar, but when the flocculent character of her sands is regarded, and the uncertainty attendant on the best devised scheme of combined dredging and reclamation, with the great peril in case of failure, some ground is seen for her apparent quiescence. The example of the Seine estuary, where the remarkable changes, due to reclamation works almost threaten the commercial position of Havre, is a case in point. The deep-water channels of the Thames estuary, beyond buoying and lighting, with some dredging of the upper reaches, have been left to natural agencies alone, and, as we have seen, the filling up of one channel has been accompanied by a corresponding improvement in another, the amount of tidal water being only equal to the maintenance of a certain low water *régime.* The improvement effected by dredging in such a river is not confined to the development of the upper reaches, in which it is carried on, but also promotes the improvement of the seaward ones, by affording a receptacle for so much more tidal scouring water.

Foundations.

The foundations best adapted for the quays and locks of a deep water entrance are of varied character, determined by the differences of locality. For founding the outworks, cylinders and caissons and crib work have been employed—the first, however, is more adapted to isolated pier supports than for quay works. The author is specially interested in the first, from having inaugurated the system (since extended all over the world) for the foundations of the Royal Terrace Pier at Milton below Gravesend, now just forty years ago. Iron cylinders and of concrete have also been used both in the Thames and the Clyde, and at some of our outports for the deep water portion of the quays. An ingenious modification, by sinking rectangular hollow monoliths of concrete, has recently been used in a low water tidal basin or dock at Felixstowe, opposite Harwich, the work having been carried out for Colonel Tomline, by Mr. Henry Lee, contractor. This, of course, involves less costly plant than that required by Mr. Stoney's monoliths, which form sectional lengths of the entire quay. Caissons, again, with or without pneumatic appliance, have been more frequently used for bridge piers where great depth has been necessary. In America, crib work has been largely employed. Concrete in rough blocks as *pierre perdue,* or in square blocks set as masonry by divers, and concrete in bags with slow-setting cement lowered by skips, forming, when massed together by its own weight, a homogeneous mass, have all been used, with concrete poured in

behind polling boards *en masse*, for the superstructure above the tides. Now, all those methods must be largely developed and improved to meet the great low-water depths required, still further largely increased in many alluvial sites before a solid foundation can be obtained. But these appliances have been already described in detail in various papers, and are beyond the scope of the present paper, except for general reference.

Before concluding, the author desires to direct attention to the importance of studying well the proportional areas of tidal basin and floating dock, and with the latter of obtaining the maximum of length of quayage in proportion to area of water dockised. The necessity for these studies is enhanced in the case of a perfectly non-tidal site, by the greatly increased objections to rising and falling with the tide, whilst loading or discharging in a tidal basin adapted to all ranges of tide from the highest to the lowest springs. These objections, intensified by all the changes going on, render more than ever necessary an inner dock with a constant level of water, whilst the loss of water, due to lockage and the difficulty of replenishing at neap tides, induces recurrences to pumping machinery for keeping up the needed constant level. A long, narrow dock, subdivided by intermediate gates, might be arranged so that the inner dock should not be subject to variations of level; but the interest on cost of such an arrangement might equal the annual cost of pumping. These are some of the considerations that occur when dealing with the subject of tidal approaches and deep-water entrances.

DISCUSSION.

The President, in opening the discussion, said that the subject was one which should be of interest to every Englishman. England was so especially a sea-girt country, that its well-being depended very greatly upon the facilities which could be provided for communicating with other countries; and there was no doubt that English steamers were more numerous, larger, and perhaps better provided than the steamers of any other nation in the world. It was, therefore, one of our duties to provide adequate accommodation for them when they arrived home.

Professor L. F. Vernon Harcourt said that the paper had gone over a very wide field. With regard to the tides around the English coast, it was well known that there were great varieties in their range. Some years ago that was specially brought under his notice while he was resident engineer of the Alderney Harbour Works. At Alderney there was a range of tide at springs of only about 17 feet, whereas at Jersey, which

was only 30 miles distant, there was a range of 32 feet. At a harbour on the Irish Coast, where he had also been resident engineer, nearly opposite the entrance to the Bristol Channel (in the upper portions of which the rise of tide was so great) there was a rise of only about 6 feet, and none at all at Courtown a little further north on the same coast. There was the well-known case of Dublin, nearly opposite Liverpool, where there was a rise of tide of only 6 feet, as compared with 31 feet at the port of Liverpool during equinoctial springs. It would not be strictly correct to say that a rise of tide was absolutely necessary for ports, because on the American coasts there were ports which had a comparatively small rise of tide. At New York, for instance, the greatest port of the United States, the rise of tide was about 6 feet. There were advantages as well as disadvantages in the absence of a range of tides. At New York, there were quays and jetties along the shores of the Hudson and East rivers, in place of enclosed docks, which he believed were unknown in the United States, except in the form of graving-docks, as the small range of tide rendered them unnecessary. He was surprised to hear from the paper that there had been any doubt in the old days about the propriety of making both sills of an entrance lock of the same depth. From his experience of the West-India Docks and the admission of vessels there, so much work was done near high water that it was most important to have the inner sill of the lock as deep as the outer sill. He could state that in the case of the south dock, both sills were exactly on the same level, but 2 feet higher than the bottom of the entrance channel at the dock end, to ensure the sills being kept free from deposit, and to allow of the meeting of the gates. One objection, indeed, raised against the lock which Mr. Leader Williams proposed for the Manchester Ship Canal, was that there was no difference in level allowed between the sill and the bottom of the channel of approach. It was noteworthy, though perhaps not surprising, that on the Thames, the general tendency has been for docks to be extended down the river, the earliest, except perhaps the Surrey Commercial Docks, being the London Docks. They had gradually crept down, until, lately, the Tilbury Docks had been constructed a long distance below London. This, however, was not the case in every port. There was a very remarkable instance of an extremely flourishing port, which was a considerable way up from the mouth of the river. He referred to the port of Antwerp. The export and import tonnage of that port were greater than that of any other except London, Liverpool, and the Tyne, and had recently increased at a greater rate than any English port. At Antwerp, the extension of docks

and quays could hardly keep pace with the advance of trade. Reverting to the docks of London, it appeared to him that the Thames was specially adapted for the construction of docks, owing to what would seem to be a disadvantage in navigation, namely, the great bends of the river. Bugsby's Marsh was the only bend of the Thames which had not been utilized for docks. It seemed possible that some docks might have been formed there, even though it was narrower than others. It had surprised him that the East and West India Dock Company did not long ago buy up the greater portion of the Isle of Dogs, where several docks could have been made with two entrances, one for the vessels coming up from the sea, and the other for up-river barges. With regard to the Millwall Docks, the paper mentioned that they were not in a flourishing condition at first. That was correct. For two or three years the Millwall Docks were simply a place for vessels to lie up in, for when the docks were first opened, there was not a single shed or warehouse on the quays, and not even a railway leading to the docks. He had had to superintend a portion of the connecting line from the Blackwall Railway, through the East and West India Dock Company's land, forming the Millwall and Blackwall Extension Railway. This, at last, gave the Millwall Company access to the railways of London. Even now the Millwall Docks were at a disadvantage compared with other docks, because they had not got an entrance down the river. Vessels using the Millwall Docks had to go past Greenwich to enter them. It would be a great advantage if they could have a second entrance in the reach near Blackwall. The new Tilbury Docks formed a very remarkable extension of dock accommodation for the Port of London. He could remember the time, during the construction of the South Dock, when the people there used to think that there would be no more docks on the Thames, and no extensions. That was seventeen or eighteen years ago, and since then the Albert Docks had been constructed, and now the large Tilbury Docks were approaching completion. People sometimes prophesied very wrongly, and it would be a great mistake at the present time to prophesy that the Tilbury Docks would be the last dock extension on the Thames. Dredging operations, to which the author had referred, had certainly received an immense extension within recent years. The Tyne and the Clyde would never have had anything like the trade which was carried on upon them without constant dredging operations. The Clyde was really a large kind of ditch, which was kept clear by dredging. About a third of the dredging operations in that river were carried on simply to maintain, not to increase the depth up to Glasgow. They were also deepening the river,

but dredging could not be discontinued. He considered it most probable that in the tidal basin at the Tilbury Docks a large amount of dredging would be required to maintain the depth, because there would always be slack water there, and consequently, constant deposit of silt. He might further mention that dredging was not only carried on in rivers, but was sometimes used to maintain an approach to a port on the sea coast itself. In the case of Dunquerque, which he regarded as one of the most interesting ports on the French coast, the entrance was absolutely dependent upon the sand-pump dredgers, which had been used so much in Holland. There were extensive sand banks in front of Dunquerque, which was a very flourishing port, and its whole existence as a port depended upon the maintenance of the entrance channel by dredging. Mr. Redman had not touched upon the injury done to the Thames by the sewage which was turned into it. The large quantity of sewage matter in the river entailed a heavy expenditure upon the dock companies of London for cleaning out their docks. They found that the amount of sludge which had to be dredged out had very greatly increased within the last few years, and the increase was undoubtedly due to the increased pollution of the river by the sewage from the outfalls. The disposal of the sewage of London in some better way was a question which was daily urgently pressing for solution some way, and it remained to be determined whether the chemists would be able to discover a cheap, efficient and convenient process for converting the sewage into a commercial product suitable for manure, or whether the ratepayers of London would be willing to expend money in carrying the sewers down to the sea. Mention was also made in the paper of quay walls being built of square hollow concrete blocks. An instance of this case was to be found at Havre in some dock extension works, now nearly completed, in which the dock walls were being built in the tideway of the Seine, by means of square hollow concrete walls, built up and sunk on the site, and subsequently filled in. As regarded the Manchester Ship Canal, which had excited a good deal of controversy in this country, the scheme which had been proposed on two occasions, for obtaining a deep water access for Manchester in the estuary of the Mersey by training walls, would, in his opinion, have been certain to entail great damage upon the port of Liverpool, because the training walls would have reclaimed a large portion of the estuary, thereby lessening the scouring power of the tide. Last session, however, instead of this, the promoters proposed what he might call an along-shore canal, so as to avoid injury to the estuary. Engineers generally considered that they could improve anything, but he was afraid that the estuary of the Mersey, in its upper

portion at least, could not be improved by means of training walls without causing injury to the estuary below. Suggestions had been made that the Liverpool bar should be removed by dredging, but, unfortunately that bar was so far out at sea that it was extremely probable that the waves would soon fill up with sand any channel that might be formed by dredging. The only alternative would be to construct extensive jetties right out to the bar. Very large works of this character had been carried out in the United States, as, for instance, at Charleston, where jetties of two or three miles in length had been constructed with willow mattresses, which can be made very cheaply in America. In the case of Liverpool, however, very expensive works would be required to improve the entrance in that way.

Captain WHARTON, R.N., alluding to Mr. Redman's criticism of the deep-water character of the entrance to the Thames, said, that surveys of the Thames were being carried on more or less continually by the Admiralty. He only wished that they had more men and more ships for the purpose, for whenever a fresh survey was made it was found that the former chart was utterly wrong, in consequence of the rapid changes that were taking place. With respect to the soundings off Leigh, the changes were unusually rapid in that part of the river. The bed was in such a state of motion that it was not worth while to sound more than the channels used by ships; but fuller surveys would be of great value to those who interested themselves in the improvement of rivers.

Mr. R. H. TWIGG said the chart of the Thames spoke for itself. The river had been left to nature with the exception of the embankments, called "walls," of the construction of which no record had been found and which, he believed, had not been altered in any way within the historic period. It was a most astonishing thing that such a chance for the exercise of engineering skill had not been made use of. His experience on the Clyde led him to think that if the River Thames had been treated as the Clyde, the dock companies would have found deep water at Woolwich and Greenwich, instead of having to go to Gravesend for it. The river simply required leading. If engineers gave it encouragement, nature would do a great deal. Had the point at Fiddlers' Reach and the bend north of Greenwich been cut off, the river would have been thereby straightened and shortened, and the present depth at Gravesend would have continued upwards to a much higher point. It was of the greatest importance to encourage the flow of the tidal wave, the speed of which was that which a heavy body would acquire in falling from the surface of the water to the centre of

gravity of the cross section. The earlier arrival of the tidal wave was, therefore, a sure indication of improvement in the channel, and showed that notwithstanding neglect, the natural scour had somewhat improved the channel. If the widths of the Thames were plotted on a straight line, it would be found that its width diminished gradually and very evenly from a width of $1\frac{3}{4}$ miles at Canvey Island to eight or nine hundred feet at Westminster. Nothing could be more favourable for encouraging a strong flow of water, and increasing the tidal oscillations that scoured out the friable bottom. He should be glad if Mr. Redman could tell them of anything of a comprehensive nature having ever been done to improve the navigation of the Thames. As to the subject of foundations, a pier on the Clyde, at Ardrossan, was extended about twenty-six years ago in the way described in the paper. He had been examining recently the mouth of the river Adour, in the south of France. This was a far more troublesome river to handle than the Thames. The immense Atlantic waves came in upon a very shifty bed of sand, and the French engineers were running out open jetties for nearly a mile in length; but these seemed to have little effect in guiding the channel, little, at least, in proportion to their cost. On the shore there was a tower with large arms, like the sails of a windmill, and these were caused to point in different directions to indicate the shifting of the channel from day to day in stormy weather, for under the influence of heavy seas the channel could not be relied upon for a single day.

Mr. W. Barns Kinsey thought that Mr. Redman had done great service in drawing attention to the much neglected Thames Haven site. He (the speaker) had had the honour of being consulting engineer to the Thames Haven Company. Mr. Twigg had drawn attention to the fact that the magnificent scour of the Thames had not been utilised to anything like its full extent. It ran out at Thames Haven, he thought, at something like five miles an hour. He believed that this portion of the river had not silted up, and that the depths remained as nearly as possible uniform in the course of years. It seemed very strange that a place long ago selected for docks, and at which works had been commenced, should have been neglected so long. He believed that at no other place could they get so good scour for keeping the dock entrance clear. If Captain Parsons would give the meeting some information as to the soundings at Thames Haven, or at Canvey Island contiguous to Leigh, to indicate whether the river at that point was silting up at all, or whether the scour to which he had referred was keeping the channel open, the information would be most valuable.

Captain PARSONS, R.N., said that he could not at that moment recollect the details with regard to the particular spot mentioned by Mr. Kinsey. He thought that Mr. Kinsey had put the flow of the tide at Thames Haven at too high a figure, and that it did not exceed four miles an hour. In fact he did not think that the velocity was more than four miles an hour anywhere in the Thames, and of course it was much less at the mouth of the estuary. The Thames was by no means so powerful a stream as the Humber, with which it has been compared.

The PRESIDENT said that the subject of the paper was becoming more and more important every day. In consequence of the increasing size of our merchant vessels, the docks which were sufficient twenty or twenty-five years ago were practically of little use for the gigantic sea monsters which were now afloat, and the tendency seemed for the size of vessels to increase still further. The members of the Society had had an opportunity of going over the Tilbury Docks last summer, and those who joined in the excursion saw what large preparations were there being made in anticipation of an increase in the size of our steamers. He had been very much struck by the remark made by Professor Vernon Harcourt that docks were only, or chiefly necessary where there were considerable tidal variations. In the Mediterranean there was practically no rise of tide at all, and there was no necessity for docks; but that was not an unmixed blessing, for the rivers which flowed into a non-tidal sea, like the Mediterranean, were much more liable to deposit silt at their mouths. It would be remembered that means had been taken to render the navigation of the Danube more perfect; but if the channel of that river was dredged out one day it was liable to become silted up the next. He did not think, therefore, that the inhabitants of the neighbourhood of the Thames had much occasion to regret having a tidal river, although it necessitated the construction of docks.

Mr. REDMAN, in reply, said that the chief criticism upon his paper appeared to be, that he had travelled over so much ground that gentleman were unprepared to deal with the various issues which had been raised. The interesting remarks which Professor Vernon Harcourt had made about tides appeared to be an endorsement of the propositions contained in the paper. Of course, docks were necessitated by the oscillations of the tide, and they were not so necessary on tideless seas like the Mediterranean. Captain Wharton, Chief Hydrographer to the Admiralty, in the few remarks which he had made, confirmed the statement in the paper as to the oscillating character of the shoals above Southend, and also the statement that for years

the channels north and south of the Leigh Middle Shoal had been alone attended to. He was sorry that Captain Parsons could not give the information which was asked of him, because he, like one of his predecessors, Captain Hewitt of the *Fairy*, had a more intimate acquaintance with the south-eastern part of our seaboard than any other officer in the service.

Mr. Twigg had remarked, with some truth, that the Thames had been left a great deal to itself; but he had, perhaps, overstated his case. No doubt the greatest works on the Thames were pre-historic, and it was a moot point whether they were Saxon or Roman. They far eclipsed our modern Thames Embankment in magnitude. We were so accustomed to see the river banks generation after generation that we were apt to forget that they were artificial, and to think that the river had been altogether neglected. London, with its tidal flow, which was undoubtedly one of the greatest blessings that it possessed, was as beautiful a city as existed in Europe, and its wealth and beauty were mainly or entirely due to the great oscillation of the tide. The tide was a great commercial carrier. The river Thames supplied London with water, but it had been victimized by being made the great drain of the metropolis. No doubt the oscillation of the tide was the great sanitary agent which purified the air and made London a seaport. There were some facts which showed that the river had not been altogether neglected. In the period from the year 1795 to 1799, the tidal oscillation was 15 feet. The oscillation now amounted to from 19 to 20 feet. The removal of old London Bridge and other bridges had admitted 25 per cent. more tidal water than there was at the end of last century. In addition to this, the time of high water had been greatly accelerated, and was now half an hour earlier in the Port of London than it was 50 years ago. Various shoals had been dredged away. The head of the deep water, carrying more than 20 feet at low water, was considerably below the Woolwich butts twenty or thirty years ago, and that head was now considerably above, as high as Charlton. The increased quantity of tidal water had caused the acceleration of the tidal flow into the river, and, added to meteorological conditions, had produced those wonderful tides which had occurred during the last few years. There had been tides at Westminster absolutely at a height of 5 feet above Trinity high water mark. The making of artificial cuts through such places as the Broadness and Margaretness would be a work of a most experimental character. The improving, deepening, and regulating of the *régime* of the existing channel would be undoubtedly the true principle and similar to that adopted by the Romans or the

Saxons in the construction of their embankments. Those embankments followed the natural course of the shore and no doubt they were formed parallel to the low water mark of the period. No doubt the river flow might be enormously increased. It might be too much increased for the benefit of London. Margaretness was well known as the site of the loss of the *Princess Alice* steamer. It was at one of those bends of the river which ought not to be navigated at all by vessels of that class after sunset, without the aid of artificial lighting. Mr. Kinsey certainly startled him by his statement as to the velocity of the tide. He (Mr. Redman) believed that 3 or 3½ knots an hour was the average maximum. So far as his observation had gone the velocity at Gravesend at half tide was seldom up to four knots. The opinion expressed in the paper as to the size of merchant steam vessels having reached a maximum was given upon the authority of naval architects who appeared to have come to that conclusion. The present subject was a hobby of his and he was much obliged for the opportunity of ventilating it which had been afforded him.

December 7th, 1885.

CHARLES GANDON, President, in the Chair.

THE DEPHOSPHORISATION OF IRON IN THE PUDDLING FURNACE.

By Philip S. Justice.

With few exceptions the present condition of the puddled iron industry in the United Kingdom is about as bad as it can be. It is not, however, within the province of the author in this paper to assign reasons for this unfortunate condition of affairs, although it may not perhaps be amiss to endeavour to show what must be the inevitable result, if the condition of one of our largest industries be not speedily changed for the better. It is well known that for several years a very large proportion of our bar iron manufacturers have not only failed to make a profit on their productions, but have been drifting from bad to worse, until their working capital has been completely exhausted in the endeavour to keep their works from being closed and practically abandoned. There are, however, a few exceptional cases, where favourable locations, or special advantages in material and quality, are such that these disastrous conditions do not prevail. But amongst most of the small mill-owners, it may be assumed as an indisputable fact that ruin has seldom or never before stared them so boldly in the face as at the present time. Now, if it can be shown by the author that good grounds of hope for redemption from this ruinous state of affairs can be reasonably entertained, through the adoption of a slightly different method of puddling, such a change will doubtless be gladly welcomed by a very large industrial portion of the community.

It is well known that a very large proportion of the iron ores mined in the United Kingdom are highly phosphoretic, so that, when converted into pig iron, the pig will be found to contain, amongst other impurities, as much as from 2 to 4 per cent. of phosphorus. In puddling such metal only a very limited percentage of this objectionable element has heretofore been eliminated, except by careful working or by employing certain

ingredients often expensive and not generally known to the ordinary puddler. As a consequence, a large proportion of the bar and plate iron which has been made from phosphoretic pig has been very poor in quality and unreliable in use, being known to the trade as "cold short" or brittle. Consequently, such iron will only fetch the lowest prices, and the profit upon it, even in better times than the present, has been hardly sufficient to induce any one to embark in its manufacture. The object of the author is to show that, even when employing the cheapest and lowest grade of phosphoretic pig iron, a most excellent quality of bars and plates can be uniformly made by employing the method of puddling devised and introduced by Mr. Joseph Beasley, of Handsworth. During the past two years—and using phosphoretic iron only—about 20,000 tons of bars, rods, &c., have been made by this process, and have proved to be of such excellent quality as to command a ready sale to chain and nail makers at remunerative prices. It, moreover, costs less to make, per ton of iron puddled, than by the ordinary process with the same iron. With these facts proved, Mr. Beasley may fairly claim to have made a great revolution in the manufacture of bar iron by the puddling process. The author ventures to assert that Mr. Beasley is as justly entitled to be considered a true benefactor as regards the puddler, as are those illustrious metallurgists whose great improvements in the manufacture of mild steel and ingot iron are so well known to all.

For more than twenty years Mr. Beasley has entertained ideas respecting the puddling of iron which he has not, until lately, had the opportunity of submitting to a practical proof. Considerable experience in the manufacture of superior qualities of iron for gun-barrels, more than a quarter of a century ago, led him from time to time to endeavour to improve the system of puddling, but not until within the last three years have his endeavours taken their present practical form. Good bars, he knew, were easy to produce when using good pig, if manipulated by good puddlers; but the problem to be solved was, how good bars could be made from what is known as common pig. It may be remarked here that an inferior and cheap description of pig iron is made in various parts of the United Kingdom from what is known as "puddlers' tap cinder," and is called "cinder pig." In tapping off puddling furnaces in the usual way, a considerable amount of cinder has been accumulated throughout the kingdom, much of which has been regarded almost as a waste product. It was estimated by the late Sidney Gilchrist Thomas that not less than three millions of tons of this tap cinder existed in Staffordshire alone. To a comparatively limited extent, this cinder (although carrying from 45 to 55 per

cent. of iron, in the form of a silicate) has been and is still used in the blast-furnace like iron ore, and cinder pig is the result.

It may be asked why this cheap material is not more generally used than ordinary ore. The reply is that the market for cinder pig is a very limited one, because of its inferior quality, as the impurities concentrated in the cinder are largely left in the pig iron produced from it. These objectionable impurities are notably phosphorus, silica, and to some extent sulphur, and when found in excess they render the pig iron almost valueless to the puddler. First amongst these impurities is phosphorus, which has so strong an affinity for the iron with which it is associated, that it becomes a most troublesome task to eliminate it, and at the same time to preserve the desirable qualities of the iron unimpaired. Analysis shows that some cinder pig-irons contain over 4 per cent. of phosphorus, whilst the best description of Swedish and similarly fine qualities show hardly more than a trace. It will therefore be understood that the puddlers who endeavour to make good bars out of cinder pig have a hard task imposed upon them. True, it was known that an excessive use of lime in the puddling furnace would very materially dissociate the phosphorus from the iron, but the remedy was found to be even worse than the disease, as this excess of lime not only destroyed the furnaces rapidly, but made the iron so "red short" that it crumbled under the influence of heat, and was useless to the forgeman. Thus cinder pig seldom held a position in the market which made it profitable to manufacture or desirable to work.

But cinder pig is not the only poor metal of this class, although it ranks about the lowest in price. Northamptonshire and the Cleveland district produce also very low grades of metal from similar causes to those just stated, although the phosphorus seldom ranges much above 2 per cent. Still, it is quite enough to seriously prevent the efforts of the puddler being successful. The knowledge of these difficulties led Mr. Beasley to make many experiments in his search for a means of utilising low grades of pig iron in the puddling furnace. Having had some rather negatively good results from the use of hydrochloric acid in past years, he was led to experiment still further with this material, but in a different manner than heretofore. He knew that phosphorus oxidised and ignited at a very low temperature when exposed to the atmosphere; also, that in the presence of chlorine, it ignited at a still lower temperature, and that its affinity for this gas would be a means of withdrawing it from the iron, if it were practicable to obtain and apply sufficient chlorine at the right moment, and at a price which, for the quantity required, would render such a

method economically available. This led him to reason upon the practicability of a thorough saturation with hydrochloric acid of the lining or fettling of his furnace, as well as the slag in which the molten pig was to be worked. By these means he hoped to set free a sufficient amount of chlorine when the saturated mixture was attacked by the heat of the furnace, and thus to draw at least a portion of the phosphorus from the iron, which, combining with the chlorine, would form, in his opinion, a chloride of phosphorus; and that this, burning freely, would increase the temperature, and thus not only save coals, but also shorten the heats of the puddler. He found that a very great increase of lime, if added in proper proportions, could be used in safety as a basic addition, if it was not mingled with the saturated acid mixture with which he lined or fettled his furnace until after the hydrochloric acid had properly acted upon the fettling itself. He soon found that the hydrochloric acid must be allowed to act on the ground tap cinder or the purple ore (which he used as fettling) for several days, and that to get an uniform action throughout, this fettling material must be ground or pulverised. If the lime were applied at the same time as the acid, a chloride of calcium would be formed, and the value of the lime as a basic ingredient would be largely lost, whilst, after several days' saturation, the violent action of the acid was neutralised by its absorption in the fettling material, and ground lime could then be applied with advantage. Thus he was led to use increasing quantities of lime, until he at last succeeded in using 30 per cent. of this material without injuring the furnace sides or making the iron in the least degree red short. He also found that when the iron had begun to melt, and after the puddler had thoroughly stirred it, so that the cinder began to thicken, the addition of a few pounds of oxide of iron in the condition of rust would cause a violent ebullition, and that, by saturating this rust with hydrochloric acid, a much more thorough purification of the iron took place than when this was omitted. Iron containing 4·31 per cent. of phosphorus, treated in this way, gave metal as fine in fibre and as tough in quality as best marked bars.

Physicking iron is no new process. It has been followed almost from the first day that iron was puddled, and the varieties of physick used have been almost as varied as the articles into which the iron has been made. With few exceptions, however, iron makers never seem to have given a permanent adherence to any particular system of administering physick in the puddling furnace. The one great exception seems to have been made in the universal use of lime as a basic purifier, but the method of application has been quite

distinct from that of Mr. Beasley. The use of lime, therefore, in puddling iron is not new, neither is the use of hydrochloric acid, nor salt, nor rust, but by a new combination of these materials he has succeeded in effecting results not previously arrived at so far as is known. Nothing is more common, when any new discovery is made public which promises to be of great utility to the world at large, than to hear the exclamation, "It is not new, it was done fifty years ago by So-and-so." And yet, when investigation takes place, it is almost universally found that although a similar invention (in some respects) was made, yet the missing link which might perhaps have made it valuable never was found. It is the old story of Columbus and his egg. Had any one previously discovered this successful method of treating the lower classes of pig iron which Mr. Beasley has practised for over two years, and which has enabled the proprietor of the Bromley ironworks not only to obtain from 5 to 10 per cent. more iron bars to the ton of pig puddled than by the old method, but also to command a price varying from 10*s.* to 20*s.* per ton more (by reason of improved quality) than he had previously obtained for the same iron puddled in the old way, can it be imagined for one moment that the method would not have been steadily followed in preference to the ordinary puddling process?

Although there are those who thought the Bessemer, the Siemens-Martin, and the Thomas-Gilchrist processes would seal the fate of the puddling furnace, yet puddling has by no means become a thing of the past. A long time must elapse (if it ever arrives) before governments or shipowners will allow their chain cables or anchors to be made of mild steel or ingot iron. Few, if any, engineers would permit steel chains to be used in engineering work, however mild the steel, if the links were welded together as in iron links. Nor would they permit any large masses of metal, in which reliable strength was the great factor, to be made of mild steel welded together from small pieces, as is now done with iron. The reason for all this is obvious; it is because the molecular construction of iron is so essentially different from that of steel.

Iron is lamelliferous and fibrous, and when two pieces of it are welded together the parts interlace, and often become even more solid and strong than at any other portion of the metal. On the contrary, steel and ingot iron are granular in their constitution, and although, in the hands of skilled workmen, they may often be welded so as to bear a considerable strain, yet from their very nature they cannot be so fully relied upon as fibrous iron. Many shipbuilders do not yet believe that mild steel plates are so reliable as good iron for ships' hulls.

Armour-plates composed entirely of mild steel have not met with success, but it is the happy combination of puddled iron with steel which has given the best results. The smith will use fifty bars of iron to one of mild steel, even if at the same cost price, as he knows he can always weld the one satisfactorily, whilst the other he is not so sure of with all the care he may use.

These examples might be multiplied, but it will not be necessary to carry the argument further, to indicate that many generations will probably pass ere the puddling of iron will cease, unless some much greater advance than has even yet taken place shall be arrived at, by which mild steel or ingot iron may be made fibrous like malleable bars, so as always to ensure safe welding.

Having pointed out the importance of Mr. Beasley's process to the iron industry, the author will now describe the process itself. He would, however, premise that no change whatever is made in the puddling furnace, which should commend the process to the consideration of the millowner. The variation from the old-established usage of working the iron is simply in the character of the fettling employed and the manner of applying it in the furnace. To those who may have had no practical experience in the puddling of iron, it may be well to explain that when the furnace is to be prepared for charging the pig iron into it, lumps of ore or calcined tap cinder are placed around the inside edges or walls, and these are usually coated with powdered or ground ore. This is called the fettling, the object of which is to prevent the slag and molten metal from cutting the side walls of the furnace and also to give up a certain portion of its metallic contents to the puddled balls which are formed in the working of the molten iron, thus increasing the yield. Mr. Beasley practically follows the same plan, but he plasters over the lumps of ore or calcined tap cinder a mixture composed of ground calcined tap cinder, purple ore, or any rich ore of iron, which he saturates with about 5 per cent. by weight of hydrochloric acid diluted with warm water. This mixture is left to stand from three to four days, during which period it is turned over several times, and to it is then added from 25 to 30 per cent. of ground lime (according to the amount of phosphorus in the pig iron to be puddled), with about 5 per cent. of salt. It is then moistened with water to the consistency of a thick paste, and is ready for immediate use, in plastering over the lumps of ore or calcined cinder around the furnace edges. Over this plastering he then spreads a few shovelfuls of a dry mixture composed of one-third ground ore and two-thirds of ground squeezer or hammer slag, saturated with about 6 per cent. of

hydrochloric acid, diluted with the same weight of water as acid. This mixture is allowed to stand for about three days, so that the acid thoroughly saturates the mixture, which has in the meantime to be turned over frequently, so as to secure the uniform action of the acid on all parts of the ground ore or cinder. The mixture is allowed to become comparatively dry, and about 20 per cent. of lime is then added, with 2½ per cent. of salt, when it is applied in its dry state over the plastered lumps before alluded to.

The slag or cinder on the furnace bottom in which the molten pig is usually worked is also saturated with hydrochloric acid for about ten days, and the material used for this is usually ground tap cinder or hammer or squeezer slag, but neither salt nor lime is added to this material. This forms the bath in which the molten iron is worked and finally balled up. When the pig iron is charged into the furnace with a proper heat the melting usually occurs in about thirty minutes, when it is well stirred by the puddler, who, finding his cinder begins to thicken, adds from 6 lb. to 10 lb. of the rust of iron borings, turnings, &c., reduced to a powder by saturation with hydrochloric acid and exposed to the atmosphere for about a fortnight. As this rust causes a violent ebullition in the molten material, it is usually charged through the stirring hole in the door of the furnace. After this the customary rabbling by the puddler occurs, and the balls are withdrawn usually in from seventy to seventy-five minutes from the time of charging the pig.

One peculiarity must not be overlooked in this process, viz., the gain in weight of the ball and puddled bar over the weight obtained by other methods. In ordinarily good puddling there is a loss perhaps of about 5 per cent. in the weight of bar, as compared with the weight of pig charged into the furnace. This arises from the sand and impurities of the pig, the waste by burning, and the slagging-off of certain quantities of the iron with the cinder, forming a silicate of iron in the fluxing. In the Beasley process, however, this loss does not occur, but on the contrary a gain in weight is usually obtained of from 3 to 5 per cent. over the weight of pig charged, so that a total gain of 10 per cent. or more over the old method is by no means unusual. This is accounted for by the fact that by the new process not only is more iron gained from the fettling, but less of it is lost in the cinder than in working on the old system. Thus a ton of bars actually costs less to produce by this method than by any other known means, as the cost of acid, grinding, lime, &c., does not exceed 1*s.* per ton of iron produced. It is fair, therefore, to estimate that the actual saving

by this process of puddling must be from 2*s.* 6*d.* to 5*s.* per ton. If to this be added the further profit gained by the production of a quality of iron much superior to what has hitherto been made from the same low-priced pig, it will be evident that the gross gain to the millowner must be of a very encouraging nature, and that he may regard with indifference the prediction that the days of the puddling furnace have passed.

It should be observed that white iron is not used in any case, but only what is known as No. 3 grey iron, as containing more carbon than white. To give some idea of the qualities of the iron obtained by the Beasley process it may be stated that certificates from Lloyds' Proving House give for bars made from cinder pig analysing 3·66 per cent. of phosphorus the following results:—

Ultimate stress per square inch 24·2 tons.

Reduction of area per square inch 40 per cent. and up to 51 per cent.

Elongation 23 per cent.

Fibre (appearance at fracture) 100 per cent. fibrous; whilst a mixture of the same cinder pig with a small proportion of a better quality produced an iron which bore 26 tons tensile strain, with 48 per cent. reduction of area, and 20 per cent. elongation. These results seem to be uniformly arrived at in repeated testings of this highly-fibrous iron. In one instance, in which the iron was more thoroughly worked, 29·82 tons tensile strain was reached in a private testing, but the iron was less fibrous. The elongation in this case was 21 per cent. Such results from such materials are very remarkable, and the author ventures to say they cannot be attained by any other known system of puddling. That the process is now, and will continue to be, a success, is proved by the fact that the proprietors of the works where Mr. Beasley initiated it continue to run their entire plant with the process, making from 150 to 200 tons of bars, &c., per week. Under these circumstances, and with such proofs before them of the value of the system, it can hardly be doubted that a large proportion of the mills which are using phosphoretic iron will see how much it will be to their interest to adopt the Beasley process.

DISCUSSION.

Mr. Justice, after the reading of the paper, called attention to samples of iron which had been made according to Mr. Beasley's process. He said that Mr. Beasley had made iron for gun-barrels entirely of cinder and Northampton pig. He was accus-

tomed to find that, of barrels manufactured from the iron which had been dephosphorised by his own puddling process, the proportion of defective ones was reduced to a minimum.

The PRESIDENT said that the subject was one which must be interesting to the engineering profession all over the world. Some years ago they had been very much surprised with the theories propounded by Thomas and Gilchrist with regard to the dephosphorisation of iron and rendering it useful for almost every purpose. The process which had been described that evening appeared to be a step still further in advance, and, judging from the specimens exhibited on the table, it seemed to be a very considerable success. He was at times puzzled to understand the distinction between iron and steel. When he was a boy they used to say that if a knife would bend it was iron, and that if it broke instead of bending it was steel; but now there was very little difference between mild steel and good wrought iron. He should be glad if some member would enlighten him as to the distinction between the two. The Society was much indebted to Mr. Justice for having brought forward the paper.

By desire of the President, the Secretary then read the following communication from Mr. GEORGE SNELUS, of Workington:—

"I am obliged by your kind invitation, but regret I shall not be able to attend. I have read the description of the process referred to, and fail to see what there is new in it. Good puddling always removed the bulk of the phosphorus, but a small portion is always left in the form of slag, intermixed with the iron, causing various defects in the resulting product, as deficient tensile strength, imperfect continuity of particles, &c., &c. For this reason puddled iron can never be so good as dephosphorised metal that is cast into ingots from a fluid condition. For some purposes well puddled iron may yet be desirable, although in all probability basic steel will soon be the cheaper product.

"Even if dephosphorised iron made by the Basic process should be no cheaper than puddled iron, it surely is a great advantage to humanity to do away with the debasing and laborious work of the puddler, and for this reason alone I think we should not try to prolong the life of such a system of manufacture. Apart from these considerations, no puddling process will ever purify iron to the same extent as can be effected by the Basic, Bessemer, or Siemens processes, by either of which methods all but the last traces of phosphorus can be removed. I shall be glad if my remarks can be read at the Discussion."

Mr. JOSEPH TAYLOR, speaking as one who had been connected with the iron trade for forty years, said that when the

Beasley process was first mentioned to him, he was very sceptical about it. In so many years he had seen many proposed improvements for puddling iron, and amongst them the Danks process, which required a very expensive class of machinery. He had a very low opinion of phosphorus. It was a very obstinate and disagreeable substance, and seemed to have been created for the purpose of plaguing ironmasters. The statement that a cheap and simple process, like that of Mr. Beasley, was capable of eliminating the phosphorus altogether in the puddling furnace seemed to be too good to be true. He wrote on the subject to a friend of his at Birmingham, and told him what was reported with regard to the process. This gentleman introduced the subject on the Exchange at Birmingham, but nobody seemed to care anything about it. He (Mr. Taylor) was at Middlesbrough a few days afterwards and talked to several iron makers there about the process. One or two of them had heard of it, but they did not believe in it. One ironmaster whom he had known for many years told him flatly that it was impossible, and asserted that no chemical combination could get rid of the phosphorus. The fact was, however, that the process did get rid of the phosphorus. He said to one objector, "Your own analysis shows something like 4 per cent. of phosphorus in the pig iron, and you have only a small decimal in the bar. Where has the phosphorus gone to?" He did not get a very definite reply to this question. The gentleman to whom he put it seemed to think that if the phosphorus had gone it had not gone in an orthodox manner, and he declined to recognise the result. He (Mr. Taylor) had been very much puzzled by the conflicting opinions, and he determined to go and see the process for himself. Mr. Beasley was kind enough to give him an introduction to the manager of the works at Bromley, which were alluded to in Mr. Justice's paper. Those works were small and rather rough, and they used the ordinary puddling furnace. He arrived early in the morning when the furnace was just being prepared for a heat. It was fettled in the manner which Mr. Justice had described, and the puddler had in front of his furnace a heap of brown-looking stuff, something like the disused tan which could be seen at Bermondsey. After the furnace was fettled, the puddler plastered it with the brown stuff and made it all nice and smooth. The chemicals were mixed by the acting manager of the works, whose business it was to see that the work was carried out properly throughout the establishment. He (Mr. Taylor) examined the pig iron and found that it was very poor stuff, containing a little over 4 per cent. of phosphorus. It was what was called cinder pig. He was quite sure that in Cleveland they would never think of making it into

wrought iron at all, but it was the best pig that was on the premises. He saw 4½ cwt. weighed for the puddling furnace. The process described in Mr. Justice's paper was then completed, a further small quantity of the chemical mixture being added as the iron began to "boil," and the iron was squeezed in a rotary squeezer and shaped in a "crocodile," and then rolled into bars. He had brought some of the bars to the meeting, and he did not think that he had ever seen much better iron. It had a good fibre and every quality that was wanted. He saw some of it that had been made into gun-barrels, and these presented the usual watered or damascene appearance. He thought that it was a very good process which would enable them to make gun-barrels out of cinder pig, and he did not know how it was that the scientific people seemed to set themselves against it. He had read that day that one gentleman said that it was utterly impossible for hydrochloric acid to eliminate phosphorus. Possibly that was correct, and yet the use of hydrochloric acid might enable them to use some other material which would eliminate the phosphorus. If the result was obtained, the method did not much matter. Mr. Justice had shown that the use of hydrochloric acid made it possible to use 20 or 30 per cent. of lime in the puddling furnace, without rendering the iron red-short. He did not wish to speak dogmatically, not being himself an iron maker (and people ought to know their own business best), but he certainly was surprised at the apathy of iron makers who would not give the process a trial, or even go to see it carried on. He hoped that the reading of this paper would have the effect of drawing attention to it. The manager of the works which he visited told him that, if the process was given up, he thought he should resign his situation and the men would strike. The men would not now consent to do without the "physick." They got a heat in less time, and they obtained an increase of weight, which meant an increase of wages, and there was no addition to the labour of puddling. Four and a half cwt. of pig would yield, by this process, nearly 5 cwt. of puddled bars.

Mr. Justice said that one eminent chemist had stated that the use of hydrochloric acid was superfluous, and that exactly the same results could be produced if water was used. Mr. Beasley had tried water over and over again, and the result had been wretchedly poor iron, utterly unfit to be sent into the market. It seemed preposterous for theoretical managers or chemists to make such assertions with regard to processes which they had never really tried. Referring to the communication from Mr. Snelus that had been read, he could quite understand

that Mr. Snelus, from his point of view as a steel maker, could not see the advantage of the process, since its purpose was to improve the puddling of iron.

Mr. A. E. Tucker said that, in discussing Mr. Justice's paper, it would be obvious that the leading point in it was the use of hydrochloric acid. When the subject was first mentioned to him, he entirely disbelieved that any advantage could attend its use, and he was still inclined to consider that the reasons given for its beneficial action were insufficient and wrong. There were, however, two reasons—and they appeared to him to be the only ones—why it could be of service. They were, first, that sulphur would be partially removed as sulphuretted hydrogen, for it was well known that hydrochloric acid would decompose sulphide of iron, and that the sulphur would go off in the form of a gas. The second reason he offered was that a decomposition of the phosphoric cinder would take place. He was not prepared to say what would be the exact character of that decomposition; but it would be obvious that any such change would probably afford an easier access to the phosphorus which they desired to remove. In that decomposition the protracted action of the acid would, no doubt, play a very important part, and he thought that any shortening of the time it was allowed to remain in the cinder would diminish any virtue the acid might possess. He might further point out that, while the quantity of acid used by Mr. Beasley was utterly insufficient to furnish the chlorine which was required to remove the phosphorus as chloride, it would undoubtedly tend to split up the slag, and would thus be as the thin end of a wedge. The other details which appeared to him to be of advantage in the process were the grinding of the raw material, and the use of salt and lime. In any process such as Mr. Beasley's, the intimate mixture of the ingredients was, of course, important, on account of the fine particles presenting points of separate action. The use of salt allowed a larger percentage of lime to be used than was otherwise possible. The use of lime in the process was very important. It had been tried over and over again, but all attempts at the regular use of it in puddling furnaces had, he believed, been generally abandoned.

There would be a tendency in the case of a non-manganiferous pig to produce a red-short iron, on account of the extended elimination of the impurities. The lime used also would shorten the life of roofs and bridges. Still he thought that in the case of the class of Staffordshire pig, with which Mr. Beasley had worked, the use of lime had very considerable advantages, and would of itself largely contribute to the excellent

results which had been obtained, while the hydrochloric acid would probably assist in the way which he had described.

Mr. Beasley, in reply to Mr. Tucker's question why lime did not produce red-shortness, said he could not give any scientific reason. He had asked other chemists, and they could not explain the reason.

Mr. Percy C. Gilchrist said that he was sure that they were all very much indebted to Mr. Justice for the valuable and interesting paper he had read. There were two questions which he hoped Mr. Justice would answer in his reply, namely, what was the total weight of fettling of all kinds used, and what was the weight of slag produced, per ton of puddled bar. His own impression was that the excellent results which were obtained were certainly assisted by the large amount of fettling used, and that the ability to use lime, without obtaining a red-short bar, was due to the intimate mixture of lime and fettling that was made; for, although lime by itself was infusible and produced red-shortness, yet, when it was mixed with its own weight of oxide of iron, it formed a fusible slag, and one that could be squeezed out during subsequent manipulation. Mr. Justice and many writers seemed somewhat surprised that the displacement of puddled iron by mild steel was not more rapid. If they turned to Mr. Jeans's valuable statistics for 1884, they would find that, although the make of puddled iron was diminished by 493,000 tons, the make of soft steel ingots had increased, if his (Mr. Gilchrist's) deductions were correct, by no less than 127,000 tons; and, from what he knew of the trade, he thought that, when the figures for 1885 were made up, it would be found that mild steel had made a still further inroad into the 2,237,535 tons of puddled iron made last year.

But, be that as it might, he thought they would all agree that there was, and would be made every year, a very large amount of puddled iron that did not possess anything like the percentage of elongation and contraction of area described by Mr. Justice, namely, 23 and 51 per cent. If all the iron that could be made was as good as that, the users, and more especially the engineers, would have good cause to be thankful.

Mr. Perry F. Nursey said he thought that both the author of the paper and Mr. Beasley were to be congratulated upon the testimony which they had just received from Mr. Gilchrist in favour of the new process, inasmuch as Mr. Gilchrist was associated with the late Mr. Thomas in the Thomas-Gilchrist process. Mr. Snelus was no doubt a very high authority in these matters, but the objections which he had raised in his letter were really very general, and, in that respect, more or

less intangible. They were, however, intelligible upon two grounds. First, Mr. Snelus had always had an objection to the puddling process, and he had very properly endeavoured to introduce mechanical puddling. He was a member of a commission appointed by the Iron and Steel Institute twelve or thirteen years ago, to visit America and investigate and report upon the question. The result was the introduction of the Danks system of mechanical puddling to some extent into this country. He (Mr. Nursey) had seen that system in operation at several ironworks in England some years since, but he was not aware that it was now practised in this country. Other mechanical processes were tried with a view of mitigating the severe and degrading labour of the puddler, and he believed that some of these (such as the Joe Pickles mechanical rabble) were still at work, but not to any great extent. As Mr. Justice had observed, Mr. Snelus's second ground of objection was intelligible, inasmuch as his interest lay in the basic process. He (Mr. Nursey) would ask Mr. Justice what difference there was between the time occupied by the ordinary process and that occupied by the Beasley process. He understood that in the Beasley process the puddling took from seventy to seventy-five minutes, from the time of charging the furnace. The question of a saving of time in the arduous labour of puddling was one which ought to be considered. As to the new process itself, he did not think there could be two opinions about it, when the facts were known. It had been worked at the Bromley works for two years, and about 20,000 tons of iron had been manufactured by it there, and sold in the market at good prices and with the best results. He thought that that was about the most practical answer which could be given to all the objections raised. During the last two years he had been professionally engaged in investigating the properties of two varieties of that class of steel known as "physicked." There were many varieties of that family which were well known in Sheffield. In one of the cases investigated by him he saw an ingot cast at Cardiff by a secret process, and he took it to the locomotive works of the Taff Vale railway and had a turning tool made from it and put upon very severe work. In the result it beat tools made of the best Sheffield steel, but it did not come up to Muchet steel. That steel was now in the market and was giving satisfaction. This was an answer to those who, probably from interest in another direction, believed that such results could not be obtained from "physicked" steel.

Mr. Haldeman said that he had seen Mr. Beasley's process in operation, and confirmed the statements that had been made with regard to its good results. The heats in the puddling

furnace occupied only from an hour and ten minutes to an hour and a quarter. The heats in the ordinary process of puddling occupied from an hour and a half to an hour and three-quarters. He was accompanied to the works by a metallurgical chemist who, before he saw the process carried out, had denied that it could effect the dephosphorisation of the iron. This matter was a very practical one. If the process made it possible to produce an iron of high class from low-priced pigs, the advantage would be considerable in the present depressed state of the iron trade. Attempts had been made from time immemorial to get rid of the phosphorus by physicking the iron. Lime had been used with the result which Mr. Justice had described, but it was perfectly well known that if lime were used in excess it would render the iron utterly worthless. A process which had enabled Mr. Beasley to make thousands of tons of iron of high class from the lowest class of pigs ought to command attention. A contest had been going on for years between iron and steel. He had always held to the supremacy of a high class of iron for most uses; and if such iron could be produced at a moderate price it would make a very serious change in the contest. The whole question turned upon the veracity of Mr. Beasley's statement that he could produce a high-class iron at the cost of common iron. If this was the case, there was a very great future for the process.

Mr. W. Barns Kinsey said he supposed that when the eminent chemist told Mr. Beasley that he could do without the hydrochloric acid and produce as good a result with water, he did not tell him that he could do away with the salt as well. Did Mr. Beasley use the same quantity of salt with the water as he had used with the hydrochloric acid?

Mr. Beasley said that, after the remark had been made to him by the chemist, he worked for two or three days with lime minus the hydrochloric acid, but as he perceived the iron getting more and more red-short, he ceased working in that way. This trial satisfied him that the acid had the effect which it was stated it could not have. A question had been asked about the difference between the time occupied by his process and that taken by the old plan of puddling. With the same class of iron, in each case, his process would save at least half an hour in the heat. In his process they used a more carbonaceous iron, and that would account for a great deal of the extra weight which was obtained in the product, because the graphite in the pig would no doubt reduce more of the oxide, and the lime also would have an effect in that way.

Mr. Nursey said that the reduction in the time was certainly

a very important step in the direction of ameliorating the labour of the puddler, especially as he got more metal in a shorter time.

Mr. Cornelius Chambers said that he had the general management of the works at Bromley which had been referred to. The results were before the meeting in the samples upon the table. Mr. Gilchrist had referred to the cost of the fettling. As far as his (Mr. Chambers's) experience had gone, the cost of this item was not increased by Mr. Beasley's process. As to the time of puddling, he believed that Mr. Beasley was correct in saying that his process required from twenty minutes to half an hour less than the ordinary method. He had been very cautious in making experiments before adopting Mr. Beasley's process at his works. They were never disposed to lavish money in the way of patents. He tried the process first at one furnace, and then having obtained a satisfactory result he tried at a second furnace, and so he went on until he was satisfied that the thing was perfectly right and safe. He had now erected a proper place for mixing the fettling, and adopted Mr. Beasley's process throughout the whole of the works. He had had it in use for two or three years, and was so satisfied with its success that he should not think of changing. The iron he used was South Staffordshire pig. He should be pleased at any time to allow any gentleman to see the process carried out at his works, and he would give him an opportunity for the fullest investigation. As one speaker had remarked, the works were very crude ones. They did not contain any very elaborate appliances; but they answered their purpose, and, in these times, the owners did not feel disposed to spend much money in improving them.

Mr. Bernays asked the last speaker how many heats he could get out of one fettling? That would affect to a great extent the cost of the labour. The meeting had heard nothing of the cost of getting the iron out of the furnaces by the new arrangement. There was no doubt that Mr. Beasley had introduced a process which was extremely neat, and the fact of its having succeeded was the best answer to those who disparaged it. He would suggest to Mr. Beasley that he should associate himself with a chemist in order that he might find out the real reason of the efficacy of the process.

Mr. George Allan said that he had been very pleased with the paper. He happened to know a good deal about the process, and had had some experience with it. The matter was brought to his notice about two years ago by Mr. Justice, and he was very much interested with the idea of making, from cheap cinder pig, iron as good as that produced from

costly pig. He was the general manager of works in Staffordshire and North Wales (New British Iron Company), and he had had opportunities of knowing something about iron of various classes. He had some of Mr. Beasley's fettling material sent to his works in Staffordshire and tried with fairly good iron, but not the best pig. On testing the finished iron he could not see that it was better than the same pig puddled in the ordinary way. Mr. Beasley explained then that it was hardly to be expected that much improvement would be effected in good iron, such as he regarded the pig in question. In judging an iron, persons were apt to assume that a high tensile strain was necessarily an indication of a first-class iron, but practical men knew that as a rule that was by no means the case. A good iron ought to possess three if not four qualifications. With a reasonably high tensile strain it ought to combine a good percentage of elongation, and reduction of area (of which engineers were generally very fond), and good welding qualities. An iron possessing a tensile strain of 28 tons per square inch might be the greatest rubbish in the world. Being utterly dissatisfied with the result at their Staffordshire works, he arranged with Mr. Beasley to test the process at Ruabon. Mr. Beasley went down and puddled the iron himself; but upon the finished iron being carefully tested at the Congreaves Works, no improvement was found to have resulted from the new process. The pig used in this case contained from 1·5 to 2 per cent. of phosphorus and had a considerable amount of silicon in it. The tensile tests of the bars gave the following results :—

Size of Bar.	Broke at Tons per square inch.	Percentage of Elongation on length of 8 inches.
2 × $\frac{7}{16}$	25·58	10·62
1 × 1	24·12	15·16
$\frac{3}{4}$ diam.	25·20	23·75
$1\frac{1}{8}$ diam.	25·36	28·75

The first two samples were bad. The third was good. The last-mentioned gave a good elongation, but was very cold-short, and of so brittle fracture that the quality was shown to be very unreliable. None of the fractures in the round bars were fibrous. The process gave very irregular results in these experiments, but when new methods are tried they must be prepared for disappointments. He did not think that the

process was the full success of which they had heard that evening. It was easy to show samples, and he did not attach much importance to them. They had heard of one place where the process had been used for a long time, but it did not appear that there was more than one. He should like to experiment further with the process.

Mr. Beasley said that he went to the Ruabon Works at Mr. Allan's request, and made trials with his process upon their commonest pig, from which he produced an excellent quality of iron. He was promised that the samples tested should be forwarded to him, but they were not sent, or he would have produced them to speak for themselves. Mr. Allan had said it was very easy to make samples, but he (Mr. Beasley) had produced hundreds of tons of iron equal to the samples before the meeting, and that from Northamptonshire, Cleveland, and Staffordshire cinder pig. It must be remembered that puddlers, as a rule, were prejudiced against new processes (whether they diminished their trouble or increased it), and often tried to make them fail. He could only attribute failure to ignorance, or prejudice, or some such cause.

Mr. Chambers, in answer to the inquiry which had been made as to the cost of Mr. Beasley's fettling, said that it was not more expensive than the fettling ordinarily in use. With regard to the remark that it was easy to make samples, he should like to say that the samples upon the table had been made in the presence of gentlemen who had inspected the works, and were not specially prepared for that meeting. From the British Iron Company's common pig, he had made as good iron as any marked bar in South Staffordshire, and he was prepared to do so again at any time.

Mr. Haldeman said that there was naturally a very great tenderness on the part of makers who were accustomed to produce a costly iron, at finding that an equally good material could be produced at a low price; the improvement affected them very seriously.

Mr. Allan said that he feared that he had been misunderstood. He was very much interested in the process, and should like to see it a success, but it must be submitted to the test of fair criticism and practice.

Mr. Justice, in replying upon the discussion, said that he was sincerely glad that Mr. Allan had been present, because he had helped them to thresh out the subject. Any new process that went along too smoothly was apt to be a failure. Mr. Nursey had spoken of the business of a puddler being a degrading one. It was a laborious one, but he did not regard hard work as degrading. As to the saving effected by Mr. Beasley's

process, it was rather understated in the paper. The saving of half an hour in a heat would effect a saving of one-third of the coal ordinarily required. He could not give Mr. Gilchrist the data concerning the slags, for he was not a practical puddler, though he had had some experience of metallurgy. It had been remarked in the discussion that, if the process had been such a complete success, it was very remarkable that it had only been adopted by one firm. The explanation of this was that Mr. Beasley had had to place himself in the hands of a maker who would aid and back him, and Mr. Chambers had participated in the benefit, and consequently had not been anxious to spread the process beyond his own works. It was only lately that he had felt willing that it should be made known. The samples which had been exhibited were such as could be got any day at the Bromley works. He held in his hand tests from Lloyds' Proving House, which were very different from those which Mr. Allan had shown. He admitted that, as Mr. Allan had said, there was not the same improvement effected in working good iron as poor iron, but this process was for the improvement of poor material. He believed that it would be the means of saving a large amount to small millowners, who could only use common cinder pig and similar phosphoretic iron.

The President congratulated the Society upon having had a good paper read, one proof of its quality being that it had produced a most interesting discussion. One remark which had struck him particularly in the course of the discussion was, that the quality of iron depended not only upon its tensile strength, but upon its welding properties; for he had frequently seen iron which otherwise appeared perfectly sound and good, but with which a good weld could not be made, and this also applied to steel. Certainly steel required more skill in welding it than iron, in fact he had never found good welding qualities in steel.

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